LEGACY
PARKWAY & PRESERVE

Right-of-Way Issues

in support of the
Supplemental Environmental Impact Statement

Legacy Parkway
Technical Memorandum

December 2004

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1.0 Introduction

The United States Court of Appeals, 10th Circuit remanded the Legacy Parkway Final Environmental Impact Statement (FEIS) for additional consideration of the following:

1. The Denver & Rio Grande (D&RG) regional alignment as an alternative
2. Alternative sequencing of the Shared Solution
3. Integration of the Legacy Parkway and transit
4. Impacts to wildlife
5. Practicability of a narrower right-of-way (ROW)

This Technical Memorandum has been prepared to present detailed information to be considered by the U.S. Army Corps of Engineers (USACE), the Federal Highway Administration (FHWA), and the Utah Department of Transportation (UDOT) related to the Court's ROW findings. Specifically, this memorandum presents information regarding the components of the ROW brought into question in the Court's decision—the proposed median and buffer area—with respect to planning, design, and environmental criteria. Separate technical memoranda have been developed for consideration of the other above issues raised by the Court.

1.1 Organization of the Technical Memorandum

Section 1.0, Introduction, summarizes the Court's findings to provide the context for the information on the ROW presented in this Technical Memorandum; Section 2.0, Approach, presents the methodologies employed to gather data and evaluate the issues raised by the Court; and Section 3.0, Results of the Analysis, presents information on and assessment of ROW issues raised by the Court for consideration by the USACE, FHWA, and UDOT.

1.2 Summary of Circuit Court Findings

1.2.1 Median Width

The Court's remand identified several issues related to the USACE's evaluation of the proposed median width of the Legacy Parkway project and the Clean Water Act (CWA) Section 404 permitting process, ultimately concluding that "...the USACE failed to assess rationally whether a narrower median is practicable, thereby rendering the issuance of the permit arbitrary and capricious on this basis" (UDOT 2000, Appendix I, "Section 404(b)(1) Evaluation," p. 66).

The key concerns identified by the Court in supporting their finding regarding median width are discussed below.

The FEIS did not provide a clear rationale for selecting the median width used for the ROW.

The USACE's 404(b)(1) Evaluation Report (the Report) notes the considerations for the proposed median width, concluding that a narrower median is not practicable. The reasons stated in the Report are:

- The visual impact of unsightly concrete barriers.
- The hazard created by a concrete barrier required in narrower medians.
- The water quality mitigation functions of the vegetated median.
- The public preference for a parkway-type facility.
- Failure to include the median would be inconsistent with mitigation proposed in the Final Environmental Impact Statement (FEIS).
- Failure to include the median would be inconsistent with local land use plans, which have included the project as a parkway-type facility.

However, the Court notes that the Report also includes the note that the "median width is also necessary to accommodate the possible addition of two lanes in the median (as presented in Section 2.2.1 of the FEIS)..." and that this acknowledgment "...undercuts the conclusion that anything less than a 65.6-foot median is impracticable for this four-lane highway." The Court concludes that the safety-based rationale for the median width, as presented in the Report, is "...amorphous and brought into question by [this] note."

The Court's findings regarding the above issue lead to the statement: "It is not clear whether a median of less than 65.6 feet requires a concrete barrier or only medians narrower than the average require concrete barriers. The width under which concrete barriers are needed is not quantified."

The FEIS did not evaluate the practicability of alternative water quality control methods.

The FEIS states that the vegetated median serves a water quality function in addition to safety and design considerations. If the additional travel lanes noted in item 1 above were eventually proposed, replacement of the water quality functions of the vegetated medians would be required. The Court concludes that this implies that there are other methods of water quality control other than a "large vegetated median," and that there is "...no evidence that the USACE considered whether a substitute water quality control method was practicable in the context of a narrower median."

The FEIS did not clearly support the finding that the Preferred Alternative is the least environmentally damaging practicable alternative.

The Court notes that part of the justification for a wider median presented in the Report included "...explaining why a package including several amenities would be desirable to various interests." For the purpose of this evaluation, these "amenities" that justify the wider median are assumed to be avoiding the visual impacts of a barrier and the stated objective of developing a parkway-type facility. The Court notes, "The CWA test is not, however, whether features of a proposal would make a more desirable project. Rather the Applicant and the USACE are obligated to determine the feasibility of the least environmentally damaging alternative that serves the basic project purpose. If such an alternative exists—like a highway configuration with a much narrower median because it dispenses with amenities—then the CWA compels that the alternative be considered and selected unless proven impracticable."

1.2.2 Berm and Utility Corridor

The Court stated in its opinion that "no reason is given in the USACE's ROD [Record of Decision], Section 404(b)(1) Evaluation Report or permit for why a ROW without a berm and utility corridor was not practicable.... Additionally, no explanation is given for why the ROW must be 330 feet [wide] for the entire 14 miles of the Legacy Parkway since the berm which is to be 33.1 feet [wide] is to run for only 3.2 miles." The opinion concludes that, since the purpose of the Legacy Parkway is to accommodate future transportation needs of the North Corridor, the berm and utility corridor are considered to be "...merely incidental to the Applicant's basic purpose." The Court found that the failure of the USACE to demonstrate whether a ROW without a future utility corridor or berm would be impracticable rendered the issuance of the permit arbitrary and capricious.

1.2.3 Trail

With regard to challenges to the trail component of the ROW, the Court stated in its opinion that “the [USACE] reasonably concluded that removing the trails was not practicable in light of the project’s overall purpose of meeting the transportation needs of the North Corridor in 2020; thus, the issuance of the permit is not arbitrary and capricious on this basis.”

This determination was based on the following:

> In the 404(b)(1) Evaluation, the [USACE] stated that the following issues were considered concerning the **trail** portion of the project when project features were analyzed to determine if a narrower ROW was practicable:
>
> - Meetings were held with trail interests in which it was determined that there was a need for a trail system in the Legacy Parkway to continue the Jordan River Trails;
> - The 1998 MIS [Major Investment Study] stated that there was a need for a pathway system for pedestrians, bicycle-riders, and equestrians in the study area;
> - Many people expressed the belief that a trail system was needed for use as an alternative means of transportation;
> - Failure to include a trail in the project would be inconsistent with decisions made during and in response to the NEPA [National Environmental Policy Act] process;
> - Failure to include the trail would eliminate a benefit that has been identified as needed in the context of public interest;
> - Failure to include the trail would be inconsistent with the local land use plans for the majority of cities in the study area.

1.3 Background and Explanation of the Final EIS Preferred Alternative and Alternative E ROW Width, Footprint, and Related Wetland Impacts

This section summarizes the relationship between the Legacy Parkway’s Preferred Alternative ROW width, the actual facility footprint, and related wetland impacts that are at issue in the Court’s decision and the USACE’s Section 404 permit decision under the Clean Water Act. For more information regarding the ROW and the facility footprint, see Section 3.2, Relationship between ROW Characteristics, Facility Footprint, and Wetland Impacts.

The Legacy Parkway Final Environmental Impact Statement and Clean Water Act 404(b)(1) evaluation both assumed that *all* wetlands within the proposed 100 m (328 ft) ROW (about 114 acres total) would be filled. The rationale for this ROW width is explained in Section 3.1, Legacy Parkway Right-of-Way.

To determine the wetland impacts from the Legacy Parkway alternatives analyzed in the FEIS, the area of wetlands within the ROW was estimated using a geographic information system (GIS)–based approach. During the project's planning phases, wetlands in the project area were mapped using existing data, remote sensing, and field surveys. These wetland data were integrated into a regional GIS layer of the project area. Alternatives alignments (assuming a 100 m [328 ft] ROW width and including interchange areas) were overlain on the wetlands mapping to estimate the area of wetlands within a given alignment. Using this approach, the Legacy Parkway project team determined that the Preferred Alternative ROW (100 m, or 328 ft) included about 114 acres of wetlands (based on preliminary design).

To ensure that the roadway facility could be constructed anywhere within the ROW limits, UDOT requested the Clean Water Act Section 404 permit for the entire ROW, and the FEIS and the USACE's Clean Water Act 404(b)(1) evaluation assumed that all 114 acres of wetlands within the proposed 100 m (328 ft) ROW would be filled. This determination was based on the 15% plans that were developed for the impact analysis, not on a final design. The 15% plans are routine for purposes of pre-decision environmental analysis and, after decision the design-build contractor (the "design-builder") uses the 15% plans as a basis to complete the final design. However, the actual impacts to wetlands from the proposed project would be less than the 114 acres permitted due to design flexibility (the ability to adjust the position of the Legacy Parkway facility within the ROW to avoid wetlands) and the fact that the facility's *footprint* would not occupy all of the ROW. The USACE understood this, and the 404 permit that it granted for the project stipulated that, for final design, the designer should try to minimize impacts within the ROW.[1] These factors are discussed in detail in Section 3.0, Results of the Analysis.

Following the Record of Decision, a design-build contract was awarded for final design and construction of the Legacy Parkway. In compliance with the 404

[1] Regarding wetland impacts discussed in this report, there is an important distinction between the ROW width and the footprint of the facility. The ROW is the width required to accommodate the typical section of the proposed Legacy Parkway. The footprint is that portion of the ROW that contains the facility's components and, in many locations; it does not occupy the entire ROW width. The footprint can be viewed as the "impact area" associated with the facility. The ROW width and typical section and their implications for addressing the Court's remand are discussed in detail in Section 3.0, Results of the Analysis.

permit, the final design that was developed before the injunction identified areas within the ROW where wetlands would be avoided. The design-builder made adjustments in the design to avoid impacts to wetlands while still complying with design standards. Using the GIS-based method described above, the design-builder determined that 14 acres of the original 114 acres of wetlands identified in the 404 permit could be avoided during construction. Therefore, under the pre-injunction design for the FEIS Preferred Alternative (with a 100 m ROW, or 328 ft), only 100 of the 114 acres of wetlands within the ROW would actually be impacted. For analysis purposes in this Technical Memorandum, the “baseline” level of wetland impacts for the FEIS Preferred Alternative ROW was assumed to be about 100 acres.

The 14 acres identified by the design-builder in the pre-injunction design are located primarily in the interchange areas. Because these interchange areas do not change as a result of a narrower ROW,[2] the ability to avoid impacts to wetlands in these areas is the same for all alternative ROWs looked at in this Technical Memorandum. Section 3.0, Results of the Analysis, and Table 3-3, Wetland Impacts for Alternative ROW Widths, identify this 14 acre reduction of actual wetland impacts for all narrower ROWs presented in this memorandum.

In October 2003, after publication of the FEIS, UDOT updated its standard drawings with a narrower median than what was used for the FEIS Preferred Alternative. UDOT is continually evaluating its roadway geometric standards based on ongoing research and analysis. Based on its own evaluation, UDOT decided to use the current AASHTO standard. Following these standards lets UDOT incorporate new innovations into its roadway projects with each new edition of AASHTO’s “Green Book,” *A Policy on the Geometric Design of Highways and Streets* (AASHTO 2001). Therefore, the current standards reference AASHTO.

The updated standard reduced the median width from 20 m (66 ft) to 15 m (50 ft). This narrower median changes the width of the Legacy Parkway ROW from 100 m (328 ft) to 95 m (312 ft). The 95 m (312 ft) cross-section is now being referred to as Alternative E; this is consistent with the terminology used in the Supplemental EIS. To reflect this change, the cross-section for the proposed project was adjusted around the centerline of the FEIS Preferred Alternative to a width of 95 m (312 feet).

[2] The design of the interchanges is based on the area needed to accommodate the ramps that connect to the roadway, not the ROW of the roadway itself.

To provide a comprehensive evaluation of the ROW widths, this Technical Memorandum presents an analysis of the components for the original FEIS 100 m (328 ft) ROW, the updated 95 m (312 ft) ROW (Alternative E), and several other narrower ROW options. All alternative ROWs in the Technical Memorandum are located along the proposed alignment for the FEIS Preferred Alternative.

It should be noted that UDOT has purchased much of the property that lies within the 100 m (328 ft) ROW associated with the FEIS Preferred Alternative. UDOT would continue to retain ownership of the property within this area, although the proposed ROW width now requires only 95 m (312 ft). UDOT will evaluate the property that was purchased to determine if the transportation need would require them to retain the property in the larger ROW. Property that is not needed could be sold, transferred, or retained by UDOT.

2.0 Approach

As noted in Section 1.0, Introduction, the purpose of this Technical Memorandum is to provide detailed information on the proposed Legacy Parkway ROW with regard to the criteria used by the agencies to evaluate the Legacy Parkway alternatives under the National Environmental Policy Act (NEPA) and Section 404 of the CWA.

The criteria considered in this Technical Memorandum were:

- Median width and median barrier–related criteria:
  - UDOT design standards and nationwide guidelines (for example, guidelines published by the American Association of State Highway and Transportation Officials [AASHTO]). UDOT standards are the minimum acceptable design standards. UDOT standards were developed using federal standards (AASHTO) as a guide. The local standards are based on safety, local weather conditions, maintenance needs, and professional engineering judgment specific to the area of study.
  - Direct wetland impacts.
  - Safety.
  - Water quality impacts.
- Buffer[3] criteria:
  - Safety.
  - Wetland impacts.

[3] "Buffer" is used in this technical memorandum to refer to the area between the roadway and the multi-use recreational trail. This area provides a buffer between the roadway's clear zone outside the travel lanes and the trail. The area is more appropriately referred to as a buffer area, rather than a "berm" or "future utility corridor," as it is referred to in other documents.

The process of compiling and analyzing the information presented in this Technical Memorandum was initiated by re-evaluating existing documentation of the Legacy Parkway environmental process, State of Utah and national standards and guidelines for roadway design, and current research on roadway design. The following approach was used in preparing this Technical Memorandum:

1. Review Existing Project Documents and Processes

- Review planning and engineering activities that resulted in the proposed project.
- Review existing environmental documentation including but not limited to the FEIS, the Records of Decision issued by FHWA and USACE, and the USACE's 404(b)(1) Evaluation Report and permit.
- Consider project-related changes since the environmental documents were issued and work completed before the Court's injunction, including actual impacts associated with completed construction within the ROW.

2. Review Relevant Research and Data

- Research and review planning and design standards for facilities similar to the Legacy Parkway. Review recent research on the design of roadways, trails, and other elements, particularly with respect to planning factors and criteria.
- Review highway safety data and research.

3. Assess ROW Components with Respect to Planning Factors

- Coordinate with USACE, UDOT, FHWA (collectively, "the agencies"), and other agency and consultant staff as appropriate regarding planning, design, and environmental compliance activities.
- Evaluate the median width, median barrier, and buffer-related concerns expressed in the Court's decision. Where appropriate, develop and assess alternate ROW scenarios for the agencies' evaluation.

4. Document the Findings

- Based on the above steps, address the issues raised in the Court's findings by documenting steps already taken by the agencies and steps taken by the agencies in response to the Court's findings.
- Document findings in a Technical Memorandum that will be used by the agencies in their re-evaluation/Supplemental Environmental Impact Statement.

3.0 Results of the Analysis

3.1 Legacy Parkway Right-of-Way

The FEIS, the USACE's 404(b)(1) Evaluation Report, and the FHWA and USACE's Records of Decision present summary descriptions of the proposed Legacy Parkway ROW and the planning, engineering, and environmental considerations that went into developing the ROW. A brief summary of the components of the ROW is presented below, including the dimensions of each component and the rationale for including them. The specific information related to the agencies' consideration of median width and the "buffer area" is presented in Section 3.3, Median Width Considerations, and Section 3.4, Berm/Buffer Area, Trail, and Utility Corridor Considerations.

On May 16, 2002, the Legacy Parkway was designated a Utah State Scenic Byway. The Legacy Parkway as designed was developed to provide views of the Great Salt Lake with amenities that enhance the route, such as landscaping and trail facilities. FHWA developed a policy for National Scenic Byways in response to the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). To be designated a National Scenic Byway, a highway must significantly meet at least one of six scenic byway criteria: scenic quality, natural quality, historic quality, cultural quality, archeological quality, and recreational quality. The Legacy Parkway meets four of the six criteria: scenic, recreational, natural, and cultural.

Many factors are considered in the planning and design of roadways. These factors include operational, environmental, engineering, community, economic, and safety considerations. These factors can sometimes conflict with each other, and transportation and regulatory agencies must carefully evaluate the relative benefits and drawbacks associated with these multiple factors when making decisions about transportation facilities. For example, the amount of ROW required to meet capacity and safety objectives (such as the number of lanes, median width, etc.) may cause environmental impacts or pose engineering challenges. Section 2.0, Approach, presents the criteria considered in the analysis of the Legacy Parkway ROW.

3.1.1 Cross-Section Right-of-Way Components

This section describes the cross-section used in the FEIS and the updated cross-section. The Legacy Parkway as proposed is a high-speed, controlled access roadway with an average daily traffic greater than 20,000 vehicles per day.

Cross-Section for the FEIS Alternative

The FEIS proposed a 100 m (328 ft) ROW width. Figure 3-1 and Figure 3-2 below present the cross-sections of the FEIS Preferred Alternative with and without the proposed berm. These figures illustrate the individual components that make up the ROW presented in the FEIS.

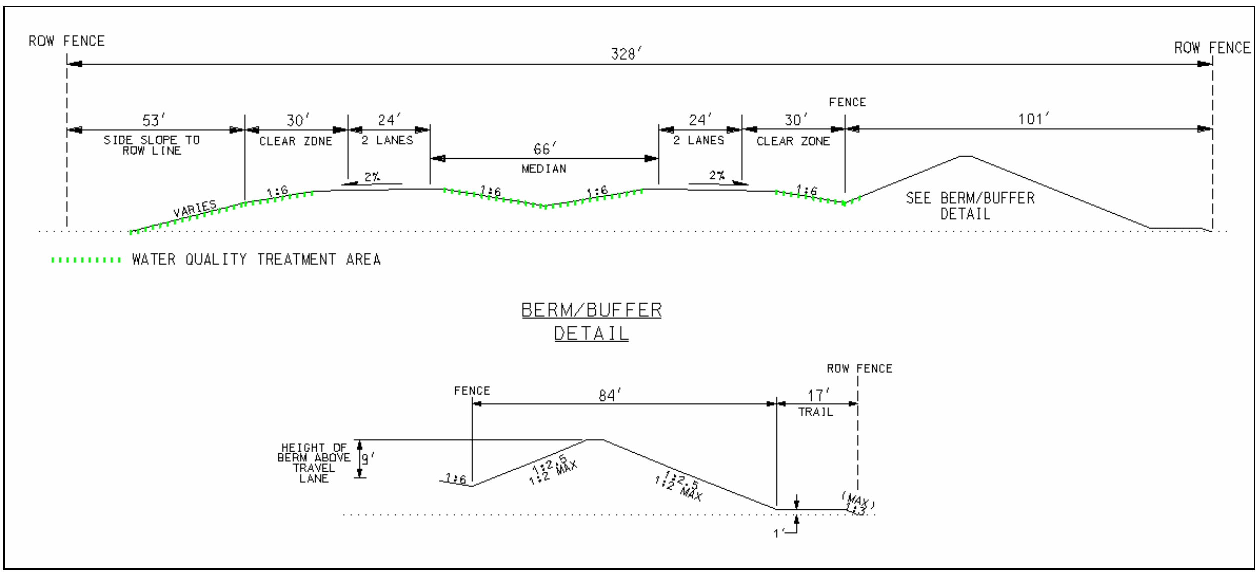

Figure 3-1. FEIS Preferred Alternative Cross-Section with Berm

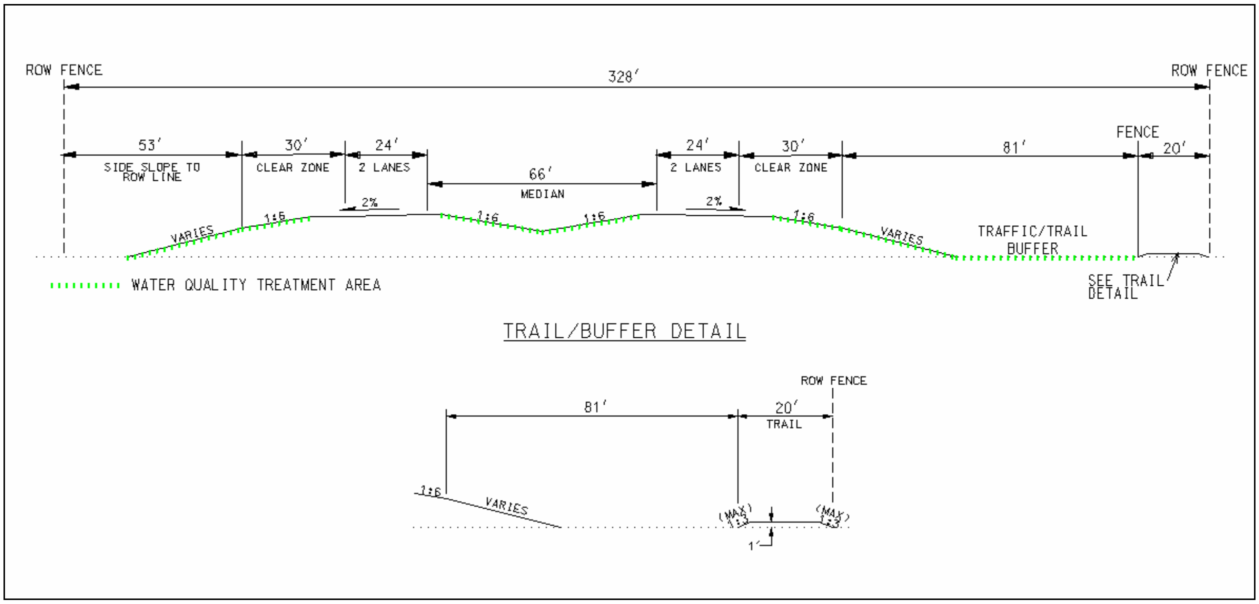

Figure 3-2. FEIS Preferred Alternative Cross-Section without Berm

Since the publication of the FEIS, UDOT has revised the standard drawing used to develop the roadway cross-section for the Legacy Parkway. Based on its own evaluation, UDOT has decided to follow the roadway geometric standards in AASHTO's Green Book (2001) because these standards are continually being researched and improved. Following these standards lets UDOT incorporate new innovations into its roadway projects with each new edition of the Green Book.

The new standard drawing, DD 4 (Appendix A), changes the widths of the median and the outside shoulder. The previous standard drawing required a 20 m (66 ft) median. The updated standard drawing directs the designer to use AASHTO guidance to determine the median width. The previous shoulder width was 3 m (10 ft), which was increased to 3.6 m (12 ft). This change does not affect the overall ROW width because it occurs within the clear zone.

Cross-Section for Alternative E

Due to the change in UDOT standards, a new updated cross-section was developed and analyzed. The revised ROW width is shown below in Figure 3-3 and Figure 3-4. The change in the median width reduced the overall ROW width by 5 m (16 ft). The new ROW width that is analyzed is 95 m (312 ft). This reduction in the median width was applied symmetrically around the centerline of the FEIS Preferred Alternative.

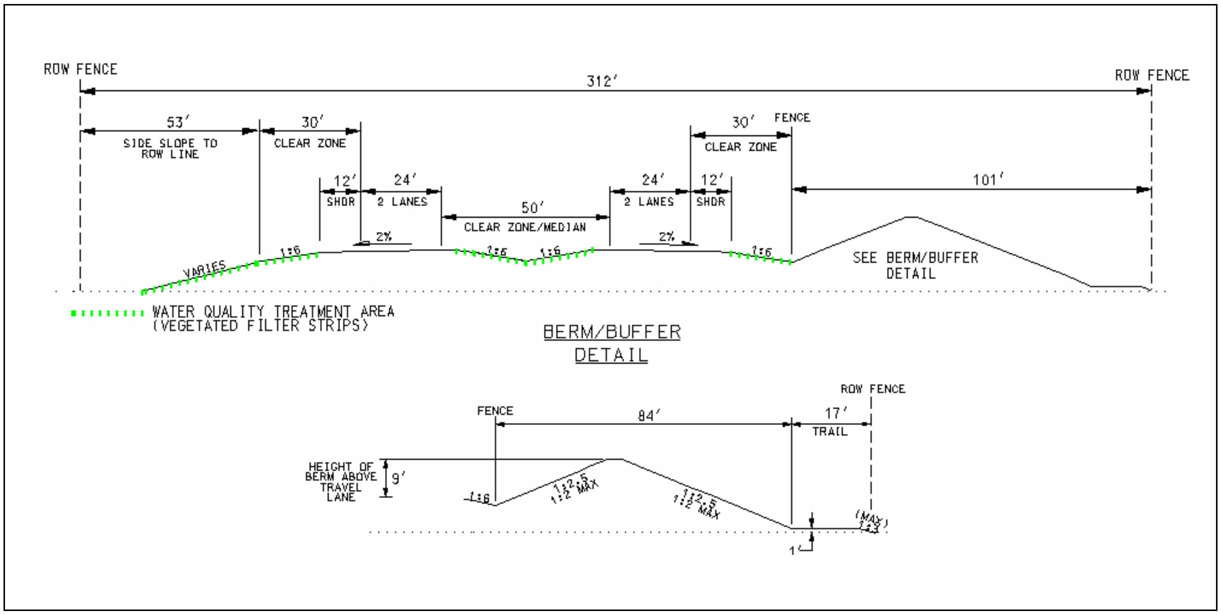

Figure 3-3. Updated Alternative E Cross-Section with Berm

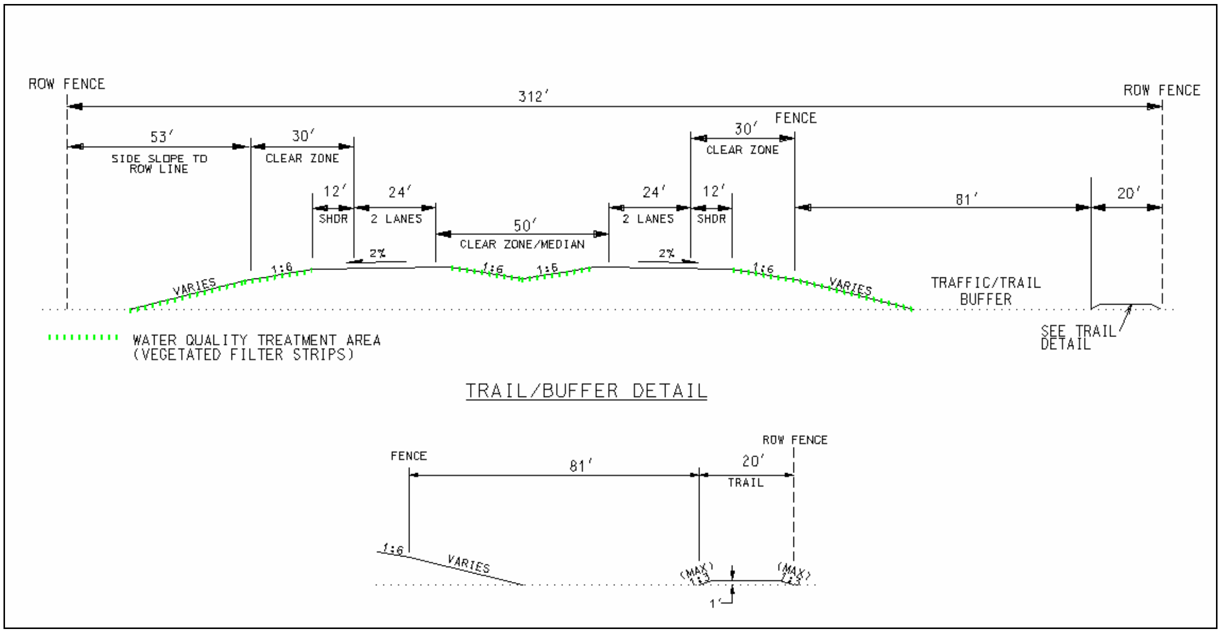

Figure 3-4. Updated Alternative E Cross-Section without Berm

The cross-sections shown above in Figure 3-3 and Figure 3-4 represent the *maximum ROW width* that would be needed to construct the Legacy Parkway facility. The *actual width* of the facility varies within that ROW width. The actual width of the facility is referred to as the footprint, which is the area that would be directly impacted by permanent highway infrastructure. The natural ground of the project area controls the fill height and thus the width of the footprint. The fill height refers to the typical height of the roadway above the existing grade. (The cross-sections above show the ROW component dimensions where 2 m [6.6 ft] of fill would be required, which is the average amount of fill required throughout the alignment.) Since publication of the FEIS, the design-builder determined some areas where fill height could be reduced to less than 1.5 m (5 ft). This reduction in fill could reduce wetland impacts in these areas because of the smaller footprint.

The side slopes outside the clear zone can vary between 1:6 and 1:3 (maximum), based on the height of the fill. UDOT's side slope requirements are 1:6 for fill heights up to 1.5 m (5 ft), 1:4 for fill heights between 1.5 m (5 ft) and 3.0 m (10 ft), and 1:3 for fill heights above 3.0 m (10 ft). UDOT's design standards do not allow a roadway side slope steeper than 1:3 due to safety and maintenance[4] requirements.

In areas where the natural ground is higher, less fill would be needed, and the footprint would be narrower. Where the natural ground is lower, more fill would be needed, and the footprint would be wider. Figure 3-6 below shows both the minimum and maximum cross-sections. The maximum height of fill that can be accommodated within the 95 m (312 ft) ROW without using walls is 6.5 m (21.4 ft). The minimum height of fill that can be used while allowing for cross pipes is 1.0 m (3.3 ft).

[4] Maintenance and access need to be provided along the entire length of the project. When this area (side slope to ROW line) is outside of the clear zone, work and maintenance can be performed without lane closures or safety hazards caused by persons or equipment within the roadway clear zone. Maintenance activities include, but are not limited to, weed control, brush cutting, vegetation control, wall maintenance, landscape maintenance, fence repair, ditch clean-out, erosion control/repair, and utility services.

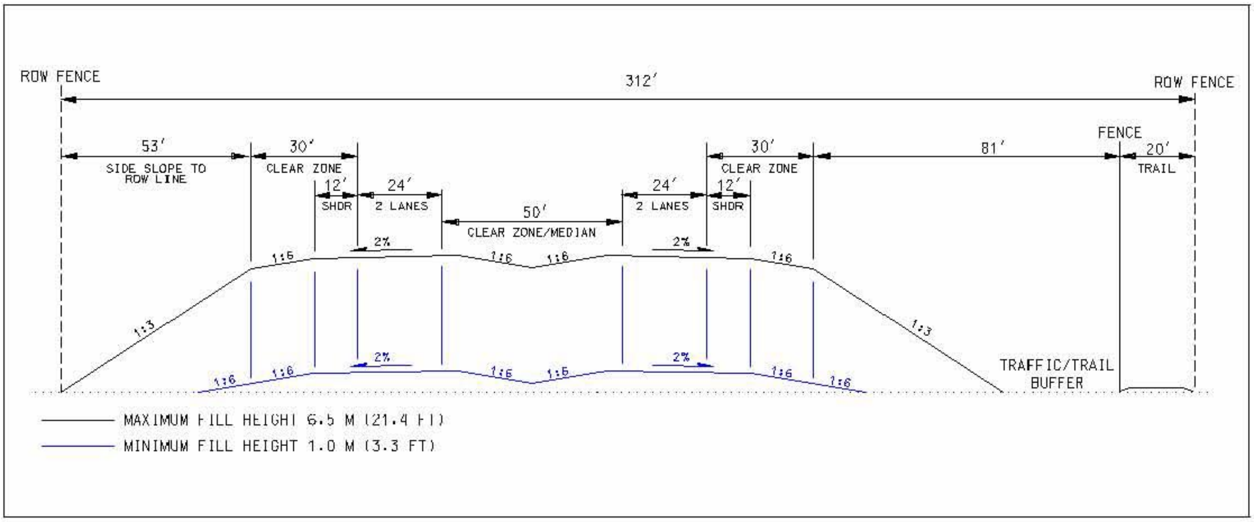

Figure 3-5. Minimum and Maximum Cross-Section within 312 ft ROW

The proposed ROW width allows variations in the horizontal alignment of the facility. This design flexibility in the horizontal alignment of the facility allows the designer to avoid impacting additional wetlands within the ROW in specific areas of concern. As part of the initial construction of the Legacy Parkway, the design-builder developed a list of wetlands within the ROW to be avoided.[5] The results of this design-builder's final design with respect to actual wetland impacts are discussed in Section 3.2, Relationship between ROW Characteristics, Facility Footprint, and Wetland Impacts.

The proposed project was set up using a design-build approach. This approach provides preliminary plans to the design-builder, who can then use these plans as a basis for developing the final design. As part of the design-build contract, the designers were encouraged to determine locations where they can further minimize impacts to wetlands within the ROW. Section 3.2.3, Alternative ROW Widths, further discusses this flexibility and how it gives the designers and contractor the flexibility to evaluate the design both in the field and in the office so that they can minimize overall environmental impacts to the greatest extent possible. There are other contracting methods available, such as design-bid-

[5] UDOT proposed a design-build approach for project delivery. This approach allowed UDOT's design-builder to refine the basic design (on which the environmental compliance documents were based) to further minimize the anticipated impacts of the project.

build.[6] A contracting method for the future Legacy Parkway design and construction has yet to be determined.

Table 3-1 and Table 3-2 below present the updated Legacy Parkway ROW components and the dimensions and design standards used to develop the typical roadway section (with and without berm) for the Legacy Parkway build alternatives.

[6] With design-bid-build project delivery, the final design is complete before the project is opened up for bidding. Once the bidding is complete, a contractor is selected to build the project.

Table 3-1. Legacy Parkway Roadway Cross-Section (with Berm) Components and Dimensions

Component (Left to Right)	Dimension, m (ft)	Standard/ Reference	Notes
Side slope to ROW line	16 m (53 ft)	UDOT[b]	• Area required to safely transition from clear zone to existing grade and for flexibility to avoid critical natural resources during construction. • Side slope varies, but depends on height of embankment—1:6 for fill heights less than 1.5 m (5 ft), 1:4 for fill heights 1.5 m (5 ft) to 3 m (10 ft), and 1:3 for fill heights above 3 m (10 ft)—and would meet UDOT minimum requirement for maintenance and access.
Clear zone (includes shoulders)	9 m (30 ft)	AASHTO[a, c], UDOT[b]	• "Clear zone" is the unobstructed area beyond the edge of the traveled way that allows for recovery of errant vehicles. • Area includes 3.0 m (12 ft) paved (outside) shoulder. • 1:6 maximum slope.
Travel lanes (southbound)	7 m (24 ft)	UDOT[b], AASHTO[a]	• Provides two southbound, 3.7 m (12 ft) travel lanes.
Median	15 m (50 ft)	UDOT[b], AASHTO[c]	• Provides safe separation distance for opposing travel lanes. • Includes 1.2 m (4 ft) paved (inside) shoulders. • UDOT's standard follows AASHTO[a] (15 m [50 ft]). • AASHTO's recommended range is 15 m to 30 m (50 ft to 100 ft).
Travel lanes (northbound)	7 m (24 ft)	AASHTO[a], UDOT[b]	• Provides two northbound, 3.7 m (12 ft) travel lanes.
Clear zone (includes shoulders)	9 m (30 ft)	AASHTO[a, c], UDOT	• "Clear zone" is the unobstructed area beyond the edge of the traveled way that allows for recovery of errant vehicles. • Area includes 3.0 m (12 ft) paved (outside) shoulder. • 1:6 maximum slope.
Berm/buffer area	27 m (84 ft)	AASHTO, safety, visual screening, noise attenuation	• Buffer width based on height of berm (2.7 m [9 ft] to provide screening). Berm side slopes (1:2 maximum) meet UDOT standards for maintenance. • Berm location: East side between 500 South and Porter Lane; west side between Glover's Lane and State Street. • Berm length: 5.1 km (3.2 mi) of overall alignment.
Trail	5 m (17 ft)	AASHTO[d]	• Provides a 2.4 m-wide (8 ft-wide) paved bicycle/pedestrian path with adjacent 1.8 m-wide (6 ft-wide) unpaved equestrian trail. There would be 0.9 m (3 ft) between the trail and ROW line.
Total ROW width	**95 m (312 ft)**		

[a] AASHTO 2001 (*A Policy on the Geometric Design of Highways and Streets*)
[b] UDOT Standard Drawing DD 4
[c] AASHTO 2002 (*Roadside Design Guide*)
[d] AASHTO 1999 (*Guide for Development of Bicycle Facilities*)

Table 3-2. Legacy Parkway Roadway Cross-Section (without Berm) Components and Dimensions

Component (Left to Right)	Dimension, m (ft)	Standard/ Reference	Notes
Side slope to ROW line	16 m (53 ft)	UDOT[b]	• Area required to safely transition from clear zone to existing grade and for flexibility to avoid critical natural resources during construction. • Side slope varies, but depends on height of embankment—1:6 for fill heights less than 1.5 m (5 ft), 1:4 for fill heights 1.5 m (5 ft) to 3 m (10 ft), and 1:3 for fill heights above 3 m (10 ft)—and would meet UDOT minimum requirement for maintenance and access.
Clear zone (includes shoulders)	9 m (30 ft)	AASHTO[a, c], UDOT[b]	• "Clear zone" is the unobstructed area beyond the edge of the traveled way that allows for recovery of errant vehicles. • Area includes 3.0 m (12 ft) paved (outside) shoulder. • 1:6 maximum slope.
Travel lanes (southbound)	7 m (24 ft)	AASHTO[a], UDOT[b]	• Provides two southbound, 3.7 m (12 ft) travel lanes.
Median	15 m (50 ft)	UDOT[b], AASHTO[c]	• Provides safe separation distance for opposing travel lanes. • Includes 1.2 m (4 ft) paved (inside) shoulders. • UDOT's standard follows AASHTO[a] (15 m [50 ft]). • AASHTO's recommended range is 15 m to 30 m (50 ft to 100 ft).
Travel lanes (northbound)	7 m (24 ft)	AASHTO[a], UDOT[b]	• Provides two northbound, 3.7 m (12 ft) travel lanes.
Clear zone (includes shoulders)	9 m (30 ft)	AASHTO[a, c], UDOT[b]	• "Clear zone" is the unobstructed area beyond the edge of the traveled way that allows for recovery of errant vehicles. • Area includes 3.0 m (12 ft) paved (outside) shoulder. • 1:6 maximum slope.
Buffer area	26 m (81 ft)	AASHTO[d], safety, visual screening, noise attenuation	• Buffer area provides safe separation between vehicle traffic on the parkway and pedestrians, bicyclists, and equestrians on the trail.
Trail	6 m (20 ft)	AASHTO[d]	• Provides a 2.4 m-wide (8 ft-wide) paved bicycle/pedestrian path with adjacent 1.8 m-wide (6 ft-wide) unpaved equestrian trail. 0.9 m (3 ft) between buffer and trail and 0.9 m (3 ft) between trail and ROW line. • Includes 1 m (3.3 ft) trail fill slope where there is no berm.
Total ROW width	**95 m (312 ft)**		

[a] AASHTO 2001 (*A Policy on the Geometric Design of Highways and Streets*)
[b] UDOT Standard Drawing DD 4
[c] AASHTO 2002 (*Roadside Design Guide*)
[d] AASHTO 1999 (*Guide for Development of Bicycle Facilities*)

In general, the components of the ROW presented above in Table 3-1 and Table 3-2 are based on UDOT's design standards (UDOT Standard Drawing DD 4; see Appendix A), which are in turn based on national standards and generally accepted engineering and design practices for roadway facilities, typically from AASHTO. This section describes each component in the same order they were presented in Table 3-1 and Table 3-2.

Side Slope to ROW Line

Side slope varies, but depends on the height of the embankment—1:6 for fill heights less than 1.5 m (5 ft), 1:4 for fill heights 1.5 m (5 ft) to 3 m (10 ft), and 1:3 for fill heights above 3 m (10 ft)—and would meet UDOT minimum requirement for maintenance and access.

Clear Zones and Travel Lanes

Dimensions of the travel lanes and clear zone follow UDOT's design standards. UDOT's design standards provide fixed-dimension widths or direct the designer to use AASHTO guidance.

Median Width

The median width is consistent with the guidelines of AASHTO's Green Book (2001) and AASHTO's *Roadside Design Guide* (2002), which together provide nationwide industry standards and guidance on the design and operation of roadways. These guidelines encourage designs tailored to particular settings or contexts. The *Roadside Design Guide* presents information on the latest state-of-the-practice in roadside safety, which is based on accident and research studies. The Green Book provides guidance by referencing a recommended range of values for critical dimensions. AASHTO's recommended range for open medians on rural freeways is 15 to 30 m (50 to 100 ft). UDOT selected a 15 m (50 ft) median due to safety concerns and traffic volumes.

The median is not intended to provide space for future travel lanes (see Section 3.3.1, Future Travel Lanes).

Berm

The berm height is designed to visually screen the roadway (see Section 3.4.2, Visual and Acoustic Buffering) from a person outside the roadway corridor (either on the trail or outside the ROW). The width used for the berm was developed using a height of 2.7 m (9 ft) and UDOT standards for side slopes (1:2 maximum non-roadway side slope). The standards for non-roadway side slopes are based on requirements for slope stability and maintenance. The berm is located along the east side of the roadway between 500 South and Porter Lane and runs along the west side of the roadway between Glover's Lane and State Street.

Buffer

The buffer width is consistent through the entire alignment for safety and water quality purposes. The berm/buffer area is not intended to provide space for a future utility corridor. For further clarification of the issue of a utility corridor, see Section 3.4, Berm/Buffer Area. The distance from the toe of the slope to the ROW line is based on UDOT design standards and maintenance requirements.

Trail

The dimensions of the trail facilities are based on AASHTO's guidelines. The trail provides non-motorized facilities for both pedestrians/bicyclists and equestrians. The trail is part of the context-sensitive design approach to transportation projects that UDOT has adopted.

Design Standards and Guidelines

Design standards and guidelines have been developed to promote the planning, design, and construction of safe and efficient transportation facilities. For this reason, it is UDOT's policy to construct all new roadways to comply with design standards. Generally, UDOT considers variations from standards only when it is upgrading existing facilities where meeting standards is not feasible.

3.1.2 Summary

- The updated cross-section is 95 m (312 ft), which was reduced by 5 m (16 ft) from the FEIS cross-section. This reduction is the result of reducing the open median from 20 m (66 ft) to 15 m (50 ft).
- The dimensions of the ROW components for Alternative E are based on UDOT standards and national planning and design guidance provided by AASHTO, as well as conditions and environmental resources in the project area.
- The proposed median width of 15 m (50 ft) is consistent with UDOT standards based on the recommended values from the AASHTO Green Book for open medians (AASHTO 2001).
- The berm area is intended to provide visual and acoustic buffering for specific areas of the alignment where UDOT has determined it is necessary.
- The berm/buffer area is intended to provide a safe separation of the trail and roadway, and visual and acoustic buffering for adjacent land uses.

3.2 Relationship between ROW Characteristics, Facility Footprint, and Wetland Impacts

This section describes the relationship between the position and width of the Legacy Parkway ROW, the facility's footprint within that ROW, and the associated wetland impacts. The Legacy Parkway project team reviewed various options for the design and use of ROW during the planning process to develop an alignment that avoided wetlands as much as possible while still maintaining a roadway geometry that would meet design and safety standards.

3.2.1 Position of Roadway within the Right-of-Way

For the purposes of planning and permitting the Legacy Parkway, the project team assumed that *all* wetlands within the ROW (113 acres total) would be filled. Originally, it was determined that the FEIS Preferred Alternative ROW (100 m, or 328 ft) would have 114 acres of wetland impacts. This determination was based on the 15% plans that were developed for the impact analysis, not on a final design. The design-builder used the 15% plans as a basis for completing the final design. This number has been reduced to 113 acres of wetland impacts as a result of reducing the ROW to 95 m (312 ft).

However, in reality, not all 113 acres would be impacted. As noted in Section 3.1.1, Cross-Section Right-of-Way Components, the designers and construction contractors are encouraged to minimize wetland impacts by creatively positioning the roadway and trail facilities within the ROW (consistent with design standards), so the actual footprint would not occupy the entire ROW width. Although the permit was requested for the entire ROW so that the facility could be constructed anywhere within the ROW limits, the actual impacts to wetlands would be less than 113 acres.

In addition, the 404 permit initially granted for the project stipulated that, for final design, the designer should try to minimize impacts within the ROW. The design-builder has identified areas within the ROW under their current design (developed before the injunction) where impacts to wetlands would be avoided due to the position of the facility within the ROW. These wetland areas are identified on the design-builder's final plans. Protective environmental fencing would be placed around the wetlands' perimeter before construction to ensure that no wetland impacts occur.

The design-builder identified 14 acres of wetlands within the ROW (primarily in the north and south interchanges) that would not be impacted during construction. The 14 acres identified by the design-builder are located primarily in the interchange areas, which will remain the same with any ROW evaluated because the design of the interchanges is based on the area needed to accommodate the ramps that connect to the roadway, not the ROW of the roadway itself. Therefore, this 14 acre reduction of wetland impacts applies to all the alternative ROW widths discussed in this section, including the 95 m (312 ft) Alternative E ROW (see Table 3-3, Wetland Impacts for Alternative ROW Widths, on page 40). Figure 3-19, Relationship between ROW Width and Wetland Impacts, on page 36 shows the relationship between ROW width and wetland impacts.

3.2.2 Design Flexibility

Design flexibility allows the designer to modify some of the facility's components (consistent with design standards) to reduce the footprint, thus avoiding some impacts to wetlands and other environmental resources within the ROW. The area required for the footprint, not the entire ROW width, determines the actual impact. UDOT uses design standards to determine the widths of the lanes, shoulders, median, side slopes, and clear zones. Following these standards and applying design flexibility, the project team developed a cross-section that would reduce the footprint's impacts on wetlands in the areas where no berm is proposed. This cross-section is described below.

The cross-section shown below in Figure 3-6 can be used as part of the design flexibility concept to minimize impacts. Using this cross-section in areas along the mainline that do not have a berm or an interchange can reduce overall impacts to wetlands. This section could not be used at locations with an earthen berm, in areas where the fill height exceeds 2 m (6.6 ft), or at the 500 South, Parrish Lane, and termini interchanges. This section could be used along about 5,140 m (3.2 miles) of the alignment. The option of breaking and steepening the slope outside the clear zone could further reduce impacts.

This cross-section would be used where the footprint crosses wetlands. In areas without wetlands, the trail would meander in the area between the roadway footprint and the edge of the ROW. This 80 m (264 ft) cross-section would be implemented within the 95 m (312 ft) ROW width. The area between the footprint and the edge of the ROW would be protected to ensure that no wetland impacts occur. Using the 80 m (264 ft) cross-section within the 95 m (312 ft) ROW allows the maximum design flexibility. The area between the footprint and the edge of the ROW can be used to meander the trail to reduce impacts to wetlands as much as possible. See Figure 3-20 and Figure 3-21 beginning on page 37 for examples of design flexibility.

The area between the footprint and the edge of the 95 m (312 ft) ROW would be protected from future impacts. The area would be owned and maintained by UDOT and protected from any future development.

80 m (264 ft) Design Flexibility Cross-Section

The project team developed a cross-section that maintains the required design elements and also has a trail (see Figure 3-6 below). This section is 80 m (264 ft) wide and includes the minimum required roadway facility and a trail. This cross-section could reduce wetland impacts by 1 to 2 acres over the 5,140 m (3.2 mi). This could potentially reduce the impacts of the 95 m (312 ft) cross-section to 97 acres. See Figure 3-19, Relationship between ROW Width and Wetland Impacts, on page 36.

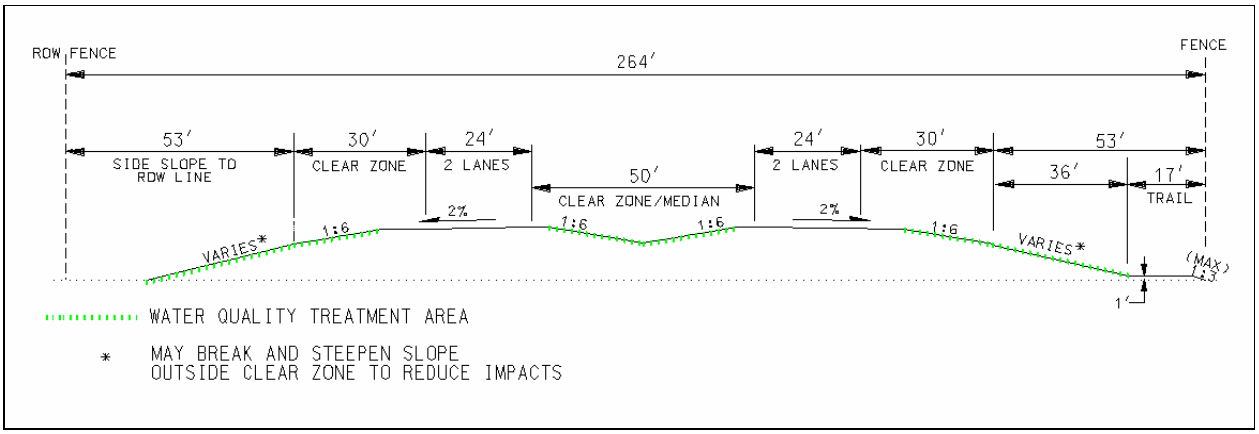

Figure 3-6. Alternative Cross-Section That Maintains Minimum Design Standards

3.2.3 Alternative ROW Widths

UDOT considered the following alternative ROW widths to assess the differences in potential impacts to wetlands:

- 89 m (292 ft)
- 87 m (285 ft)
- 80 m (261 ft)
- 71 m (234 ft)

Wetland impacts associated with each ROW are noted; impacts of the footprints would be less.

89 m (292 ft) ROW Width

An alternative was developed based on reducing the ROW width from 95 m (312 ft)—the updated width of Alternative E—to 89 m (292 ft) (see Figure 3-7 and Figure 3-8 below), by using a 9 m (30 ft) median, the minimum median width (without a barrier) allowed by AASHTO, and providing a trail and/or berm/buffer area. This does not meet UDOT design standards for median width. This alternative ROW contains 112 acres of wetlands but would only impact 98 acres of wetlands, 1 acre less than the updated Alternative E ROW (see Table 3-3, Wetland Impacts for Alternative ROW Widths, on page 40). See Figure 3-19, Relationship between ROW Width and Wetland Impacts, on page 36.

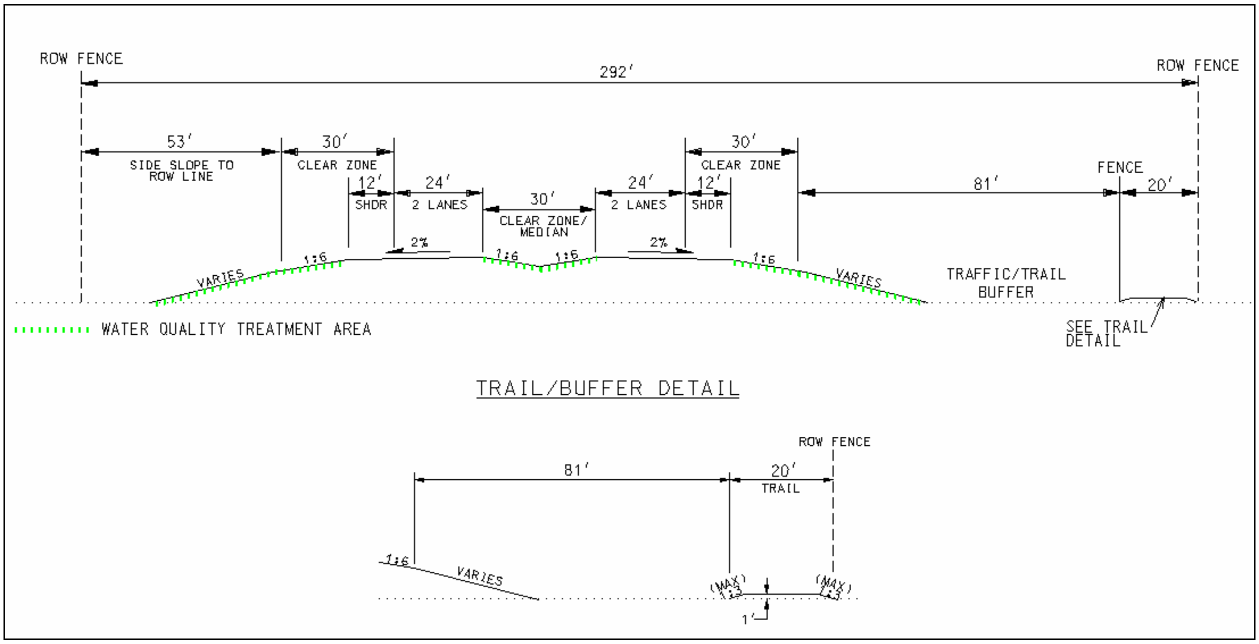

Figure 3-7. Cross-Section with AASHTO Minimum Median and Trail

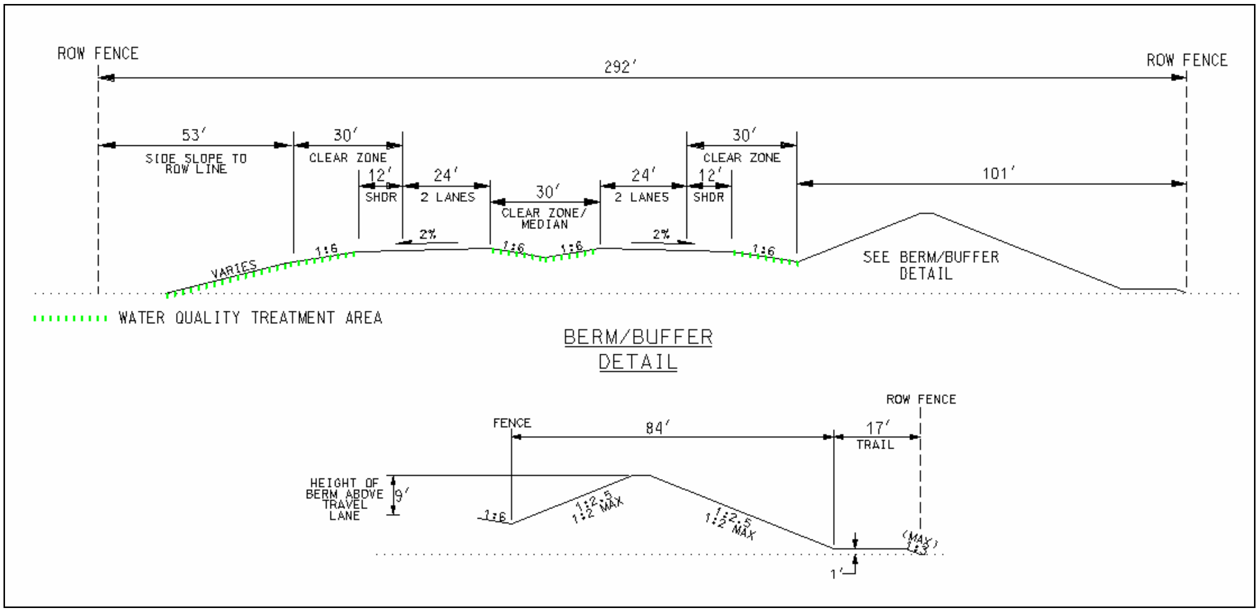

Figure 3-8. Cross-Section with AASHTO Minimum Median, Berm, and Trail

87 m (285 ft) ROW Width

One alternative is reducing the ROW width from 95 m (312 ft)—the updated width of Alternative E—to 87 m (285 ft) (see Figure 3-9 below) by reducing the median to the minimum allowable by UDOT standards and using a median barrier. This alternative would reduce the ROW width by 9% and the ROW area by about 2%.[7] (The side-slope-to-ROW line would be reduced by 1 m [3 ft] when shifting the cross-section to the center of the alignment.) This alternative ROW contains 112 acres of wetlands but would only impact 98 acres of wetlands, 1 acre less than the Alternative E ROW (see Table 3-3, Wetland Impacts for Alternative ROW Widths, on page 40). See Figure 3-19, Relationship between ROW Width and Wetland Impacts, on page 36.

[7] The total acreage required to accommodate the 95 m (312 ft) ROW is 900 acres. The acreage required for the 87 m (285 ft) ROW is 880 acres. The overall reduction of 20 acres is 2% of the 95 m (312 ft) ROW.

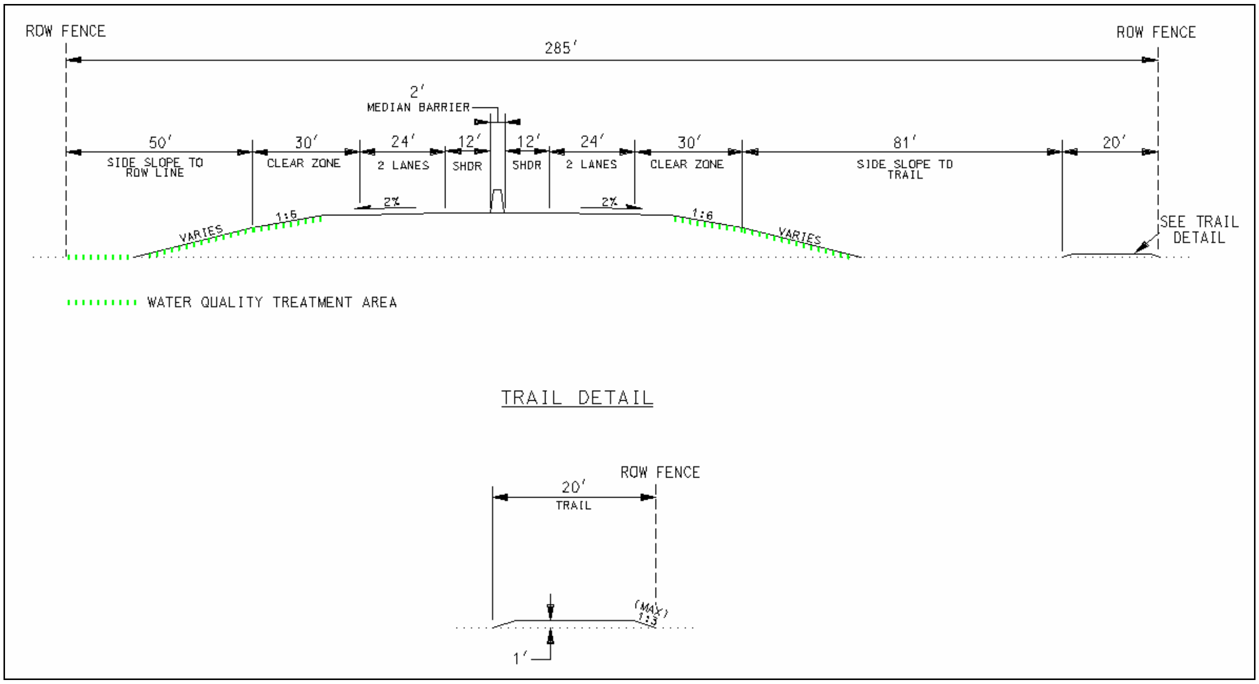

Figure 3-9. Alternative Cross-Section with a Median Barrier

Figure 3-10 through Figure 3-15 below show the entire updated Alternative E alignment overlaid on a map of the jurisdictional wetlands in the project area. These figures begin at the southern end of the project area and move north along the alignment. The figures show the curvature of the roadway, which is designed to avoid wetland impacts as much as possible.

Figure 3-16 on page 33 presents a detailed area from Figure 3-15 that shows the relationship between wetland impacts and varying ROW widths. Figure 3-16 shows that the impact on the specific wetlands within the Legacy Parkway ROW changes by 0.02 acre (the total area of the wetland is 0.8 acre) when the ROW width is reduced from 95 m (312 ft) to 87 m (285 ft).

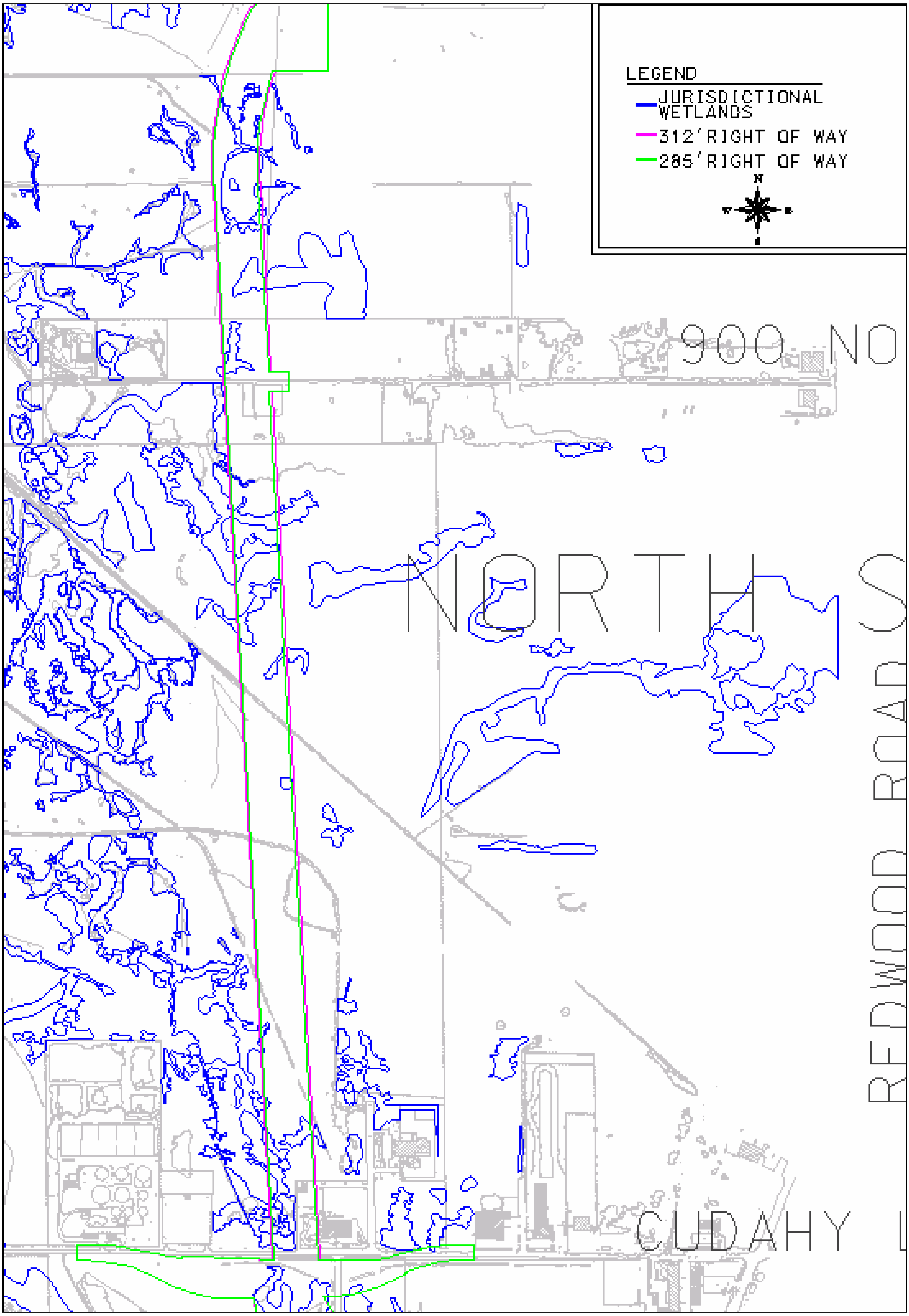

Figure 3-10. Right-of-Way and Jurisdictional Wetlands between North Salt Lake and Woods Cross

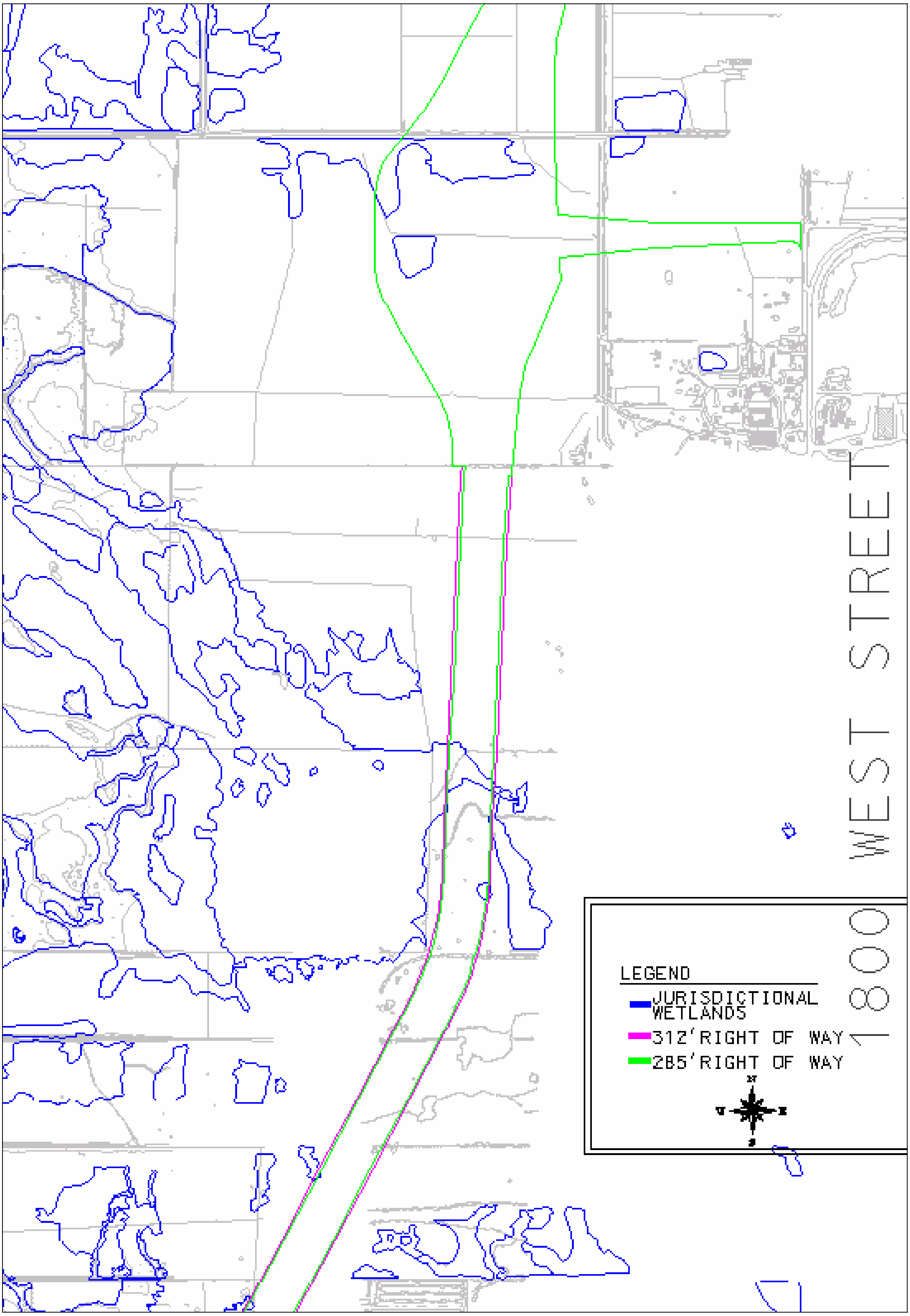

Figure 3-11. Right-of-Way and Jurisdictional Wetlands between Woods Cross and West Bountiful

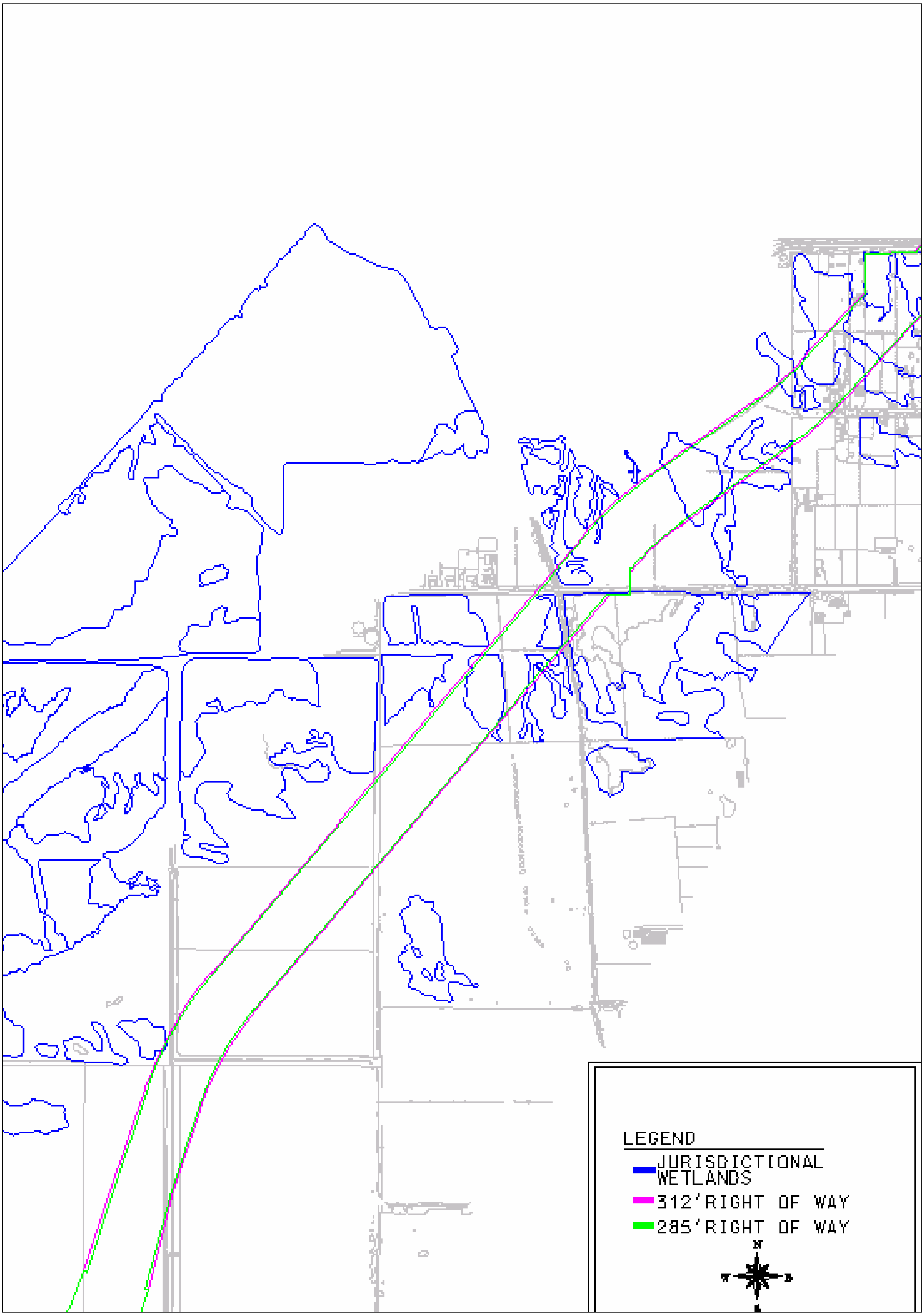

Figure 3-12. Right-of-Way and Jurisdictional Wetlands between West Bountiful and Centerville

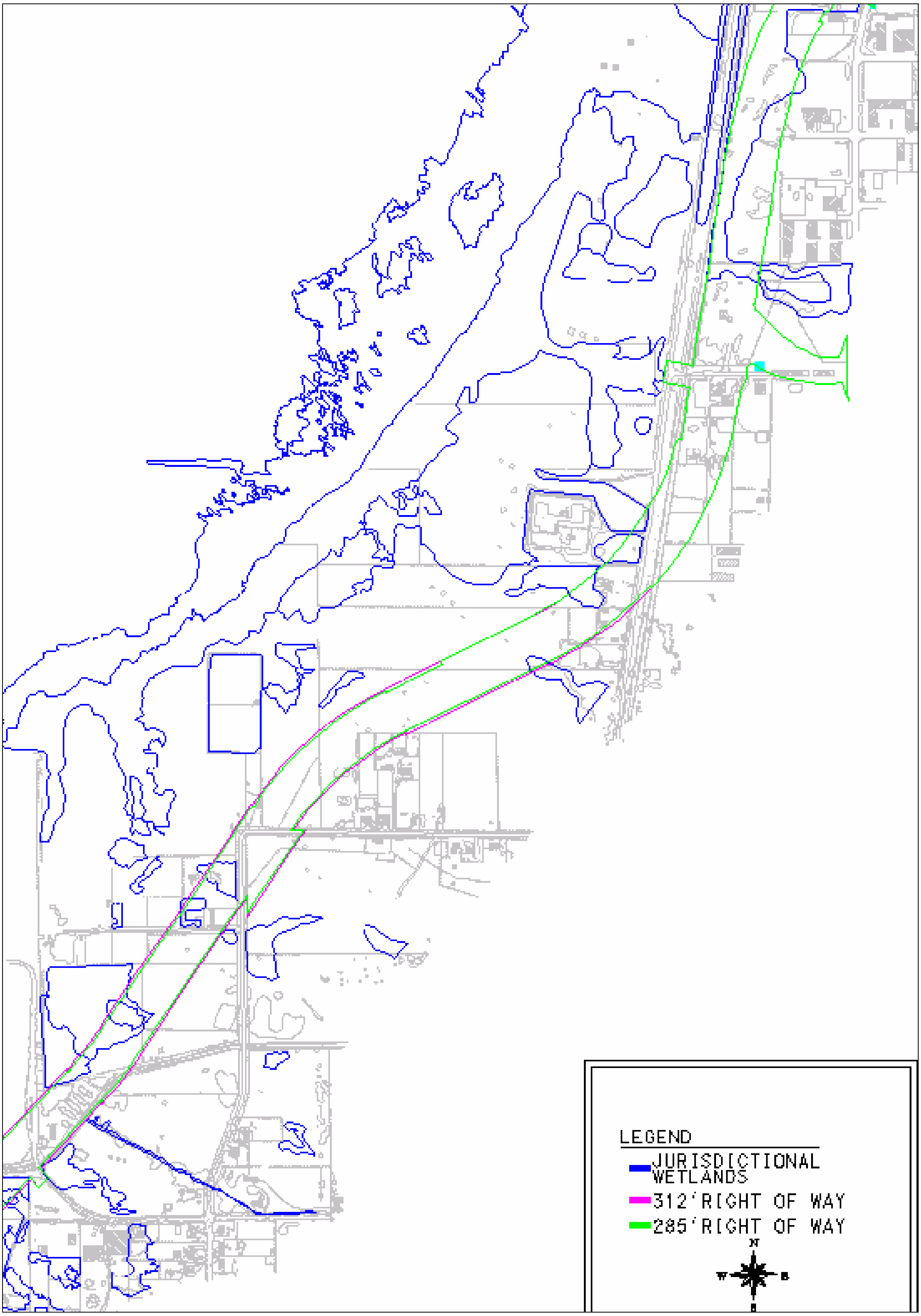

Figure 3-13. Right-of-Way and Jurisdictional Wetlands in Centerville

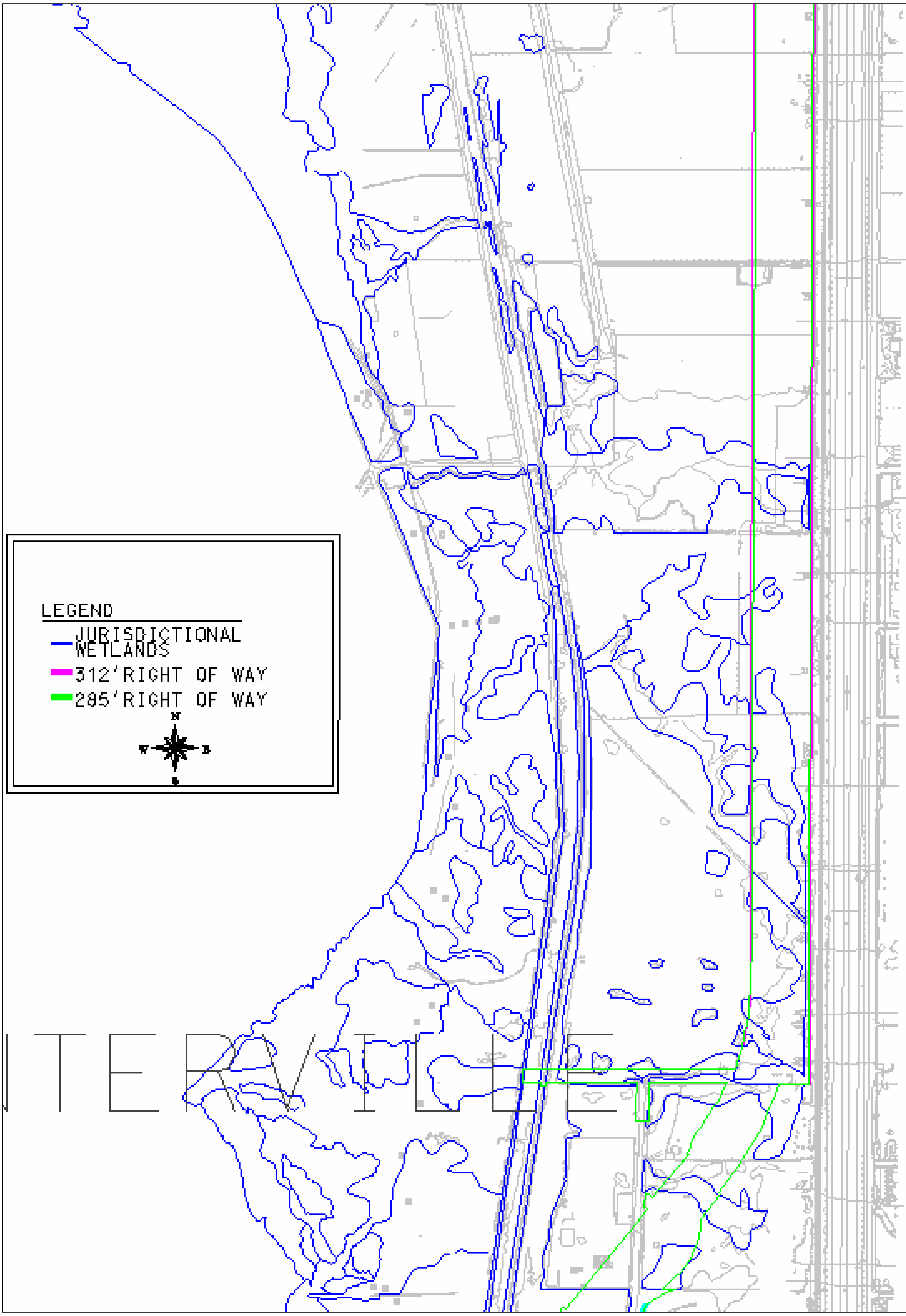

Figure 3-14. Right-of-Way and Jurisdictional Wetlands from Centerville to Farmington

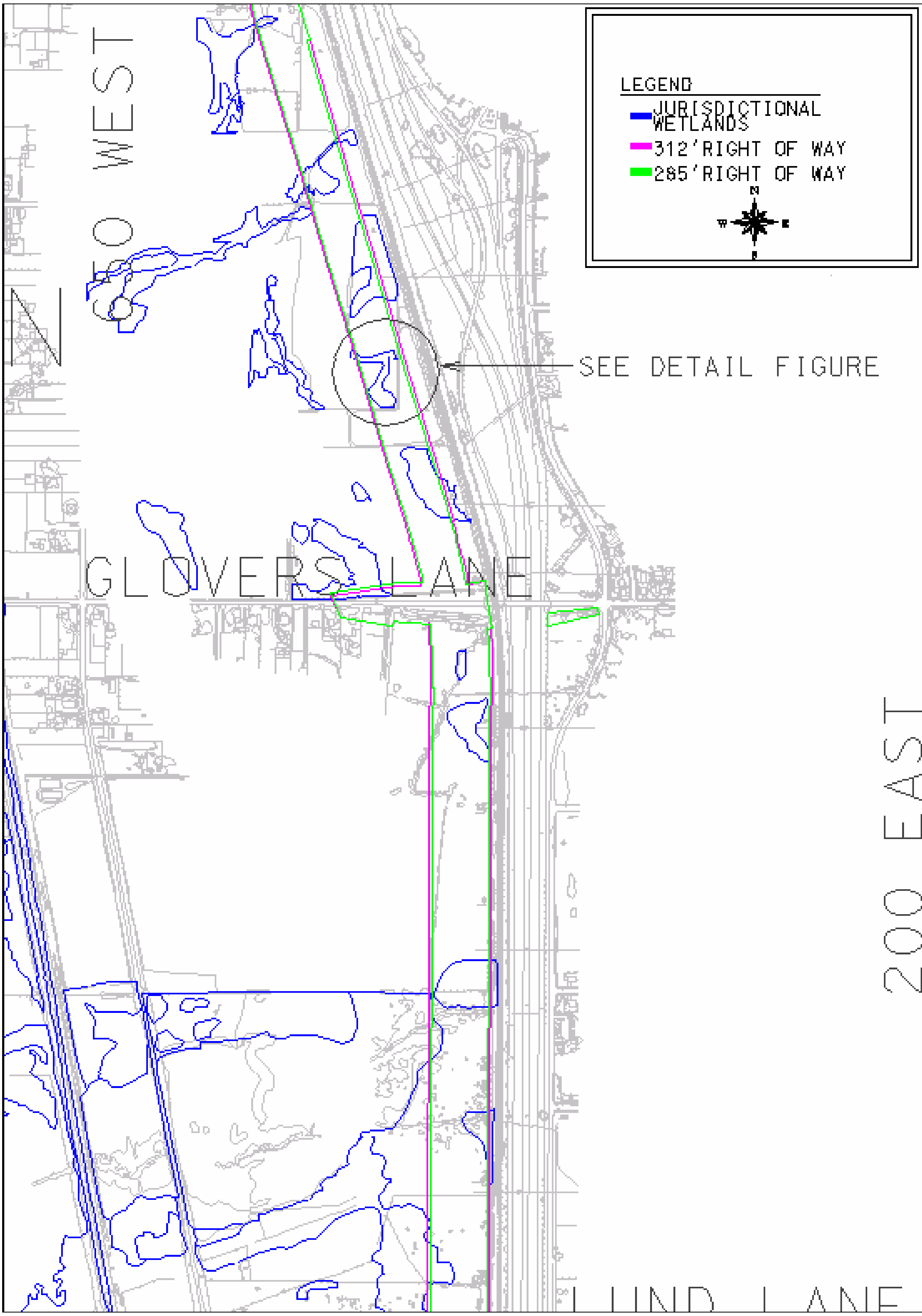

Figure 3-15. Right-of-Way and Jurisdictional Wetlands in North Salt Lake

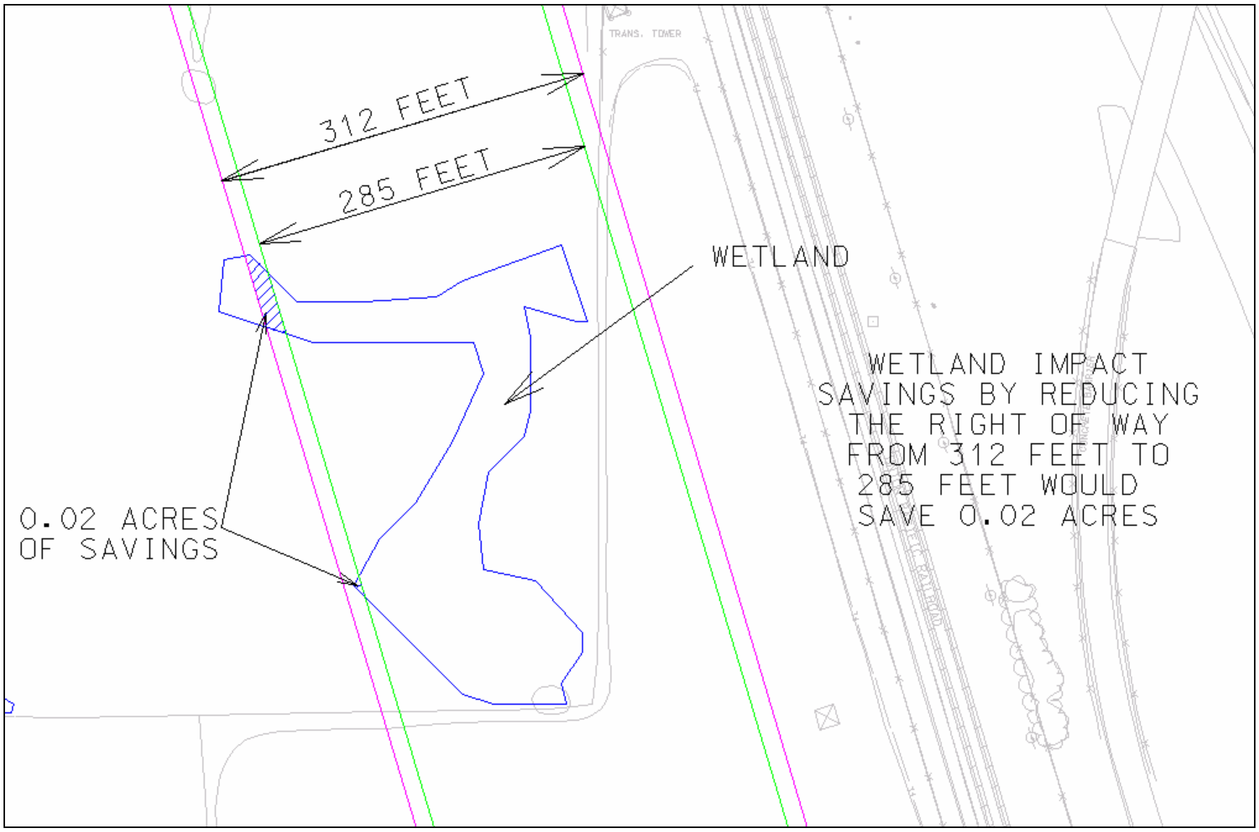

Figure 3-16. Detail of Wetland Impacts between 95 m and 87 m (312 ft and 285 ft)

80 m (261 ft) ROW Width

A reduced ROW with of 80 m (261 ft) was also evaluated (see Figure 3-17 below). This alternative ROW width was achieved by using a median barrier to reduce the median width to the minimum allowable by UDOT standards and by providing a trail but reducing the buffer area. This is the narrowest section that could be used for a four-lane highway while meeting the project's purpose and need and still following UDOT design standards.

The narrowest cross-section provides a trail (which is consistent with the project's purpose and need), but reduces both the buffer area and the open median. The trail is located next to the area required for the roadway (which meets UDOT design standards) and incorporates a 3 m (10 ft) landscaped area next to the trail. This landscaped area is needed to provide the "parkway" element of the facility and allows room for the trail to meander. This area also provides a visual buffer for trail users.

A noise wall is shown separating the trail from the roadway. Reducing the buffer area could require the use of noise walls. A complete noise study would be required to determine the exact location and size of any noise walls.

This alternative ROW contains 110 acres of wetlands but would only impact 96 acres of wetlands, 3 acres less than the updated Alternative E ROW (see Table 3-3, Wetland Impacts for Alternative ROW Widths, on page 40). See Figure 3-19, Relationship between ROW Width and Wetland Impacts, on page 36.

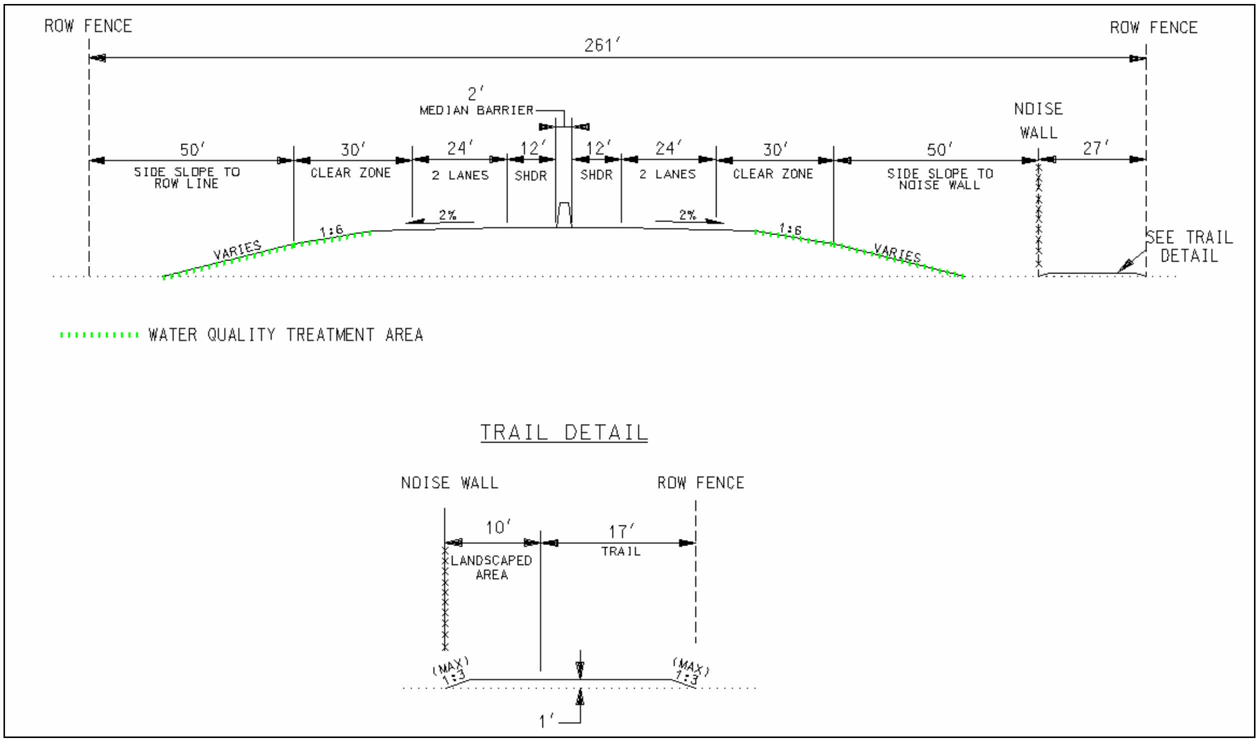

Figure 3-17. Alternative Cross-Section with a Median Barrier, Trail, and Reduced Buffer Area

71 m (234 ft) ROW Width

A narrower cross-section that does not include the trail was also developed (see Figure 3-18). This type of roadway without a trail was previously determined by USACE to be impracticable, but is included in this analysis at the request of the federal lead agencies and is provided to illustrate the wetland impacts from the trail and landscaped area itself.

This section is identical to the 80 m (261 ft) section except that the trail and landscaped area have been removed. This section is 71 m (234 ft) wide and includes only the roadway facility. This alternative ROW contains 106 acres of wetlands but would only impact 92 acres of wetlands, 4 acres less than the 80 m (261 ft) section and 7 acres less than the 95 m (312 ft) section (see Table 3-3, Wetland Impacts for Alternative ROW Widths, on page 40). See Figure 3-19, Relationship between ROW Width and Wetland Impacts, on page 36.

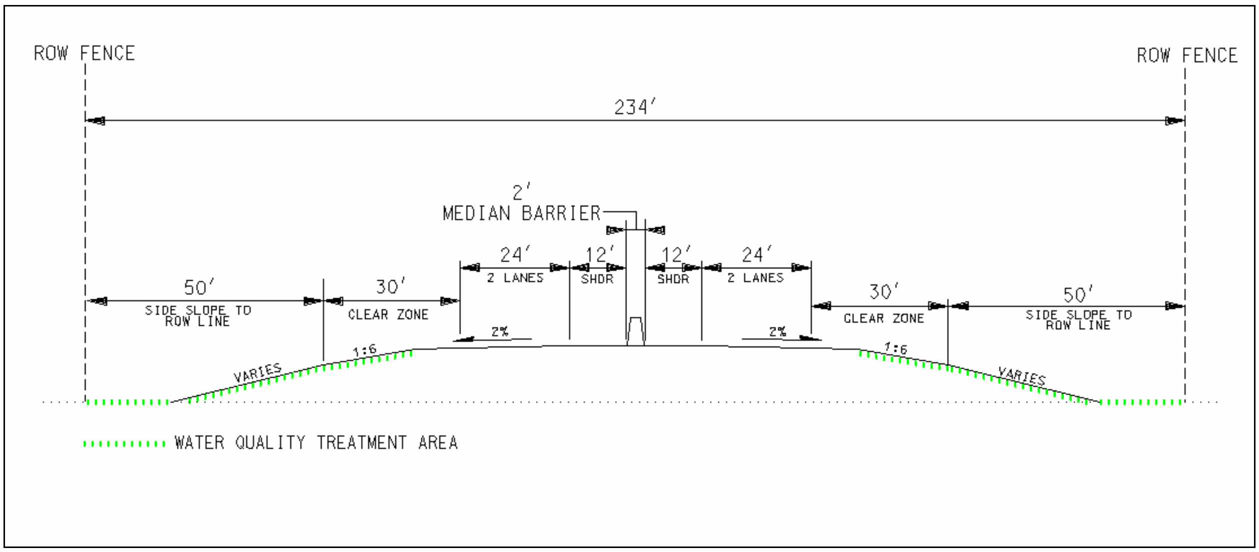

Figure 3-18. Cross-Section with a Median Barrier and No Trail

Figure 3-19 is a graphical representation of the relationship between ROW widths and wetlands impacts. The figure shows each of the ROW widths and the wetlands impacts associated with it.

Figure 3-19. Relationship between ROW Width and Wetland Impacts

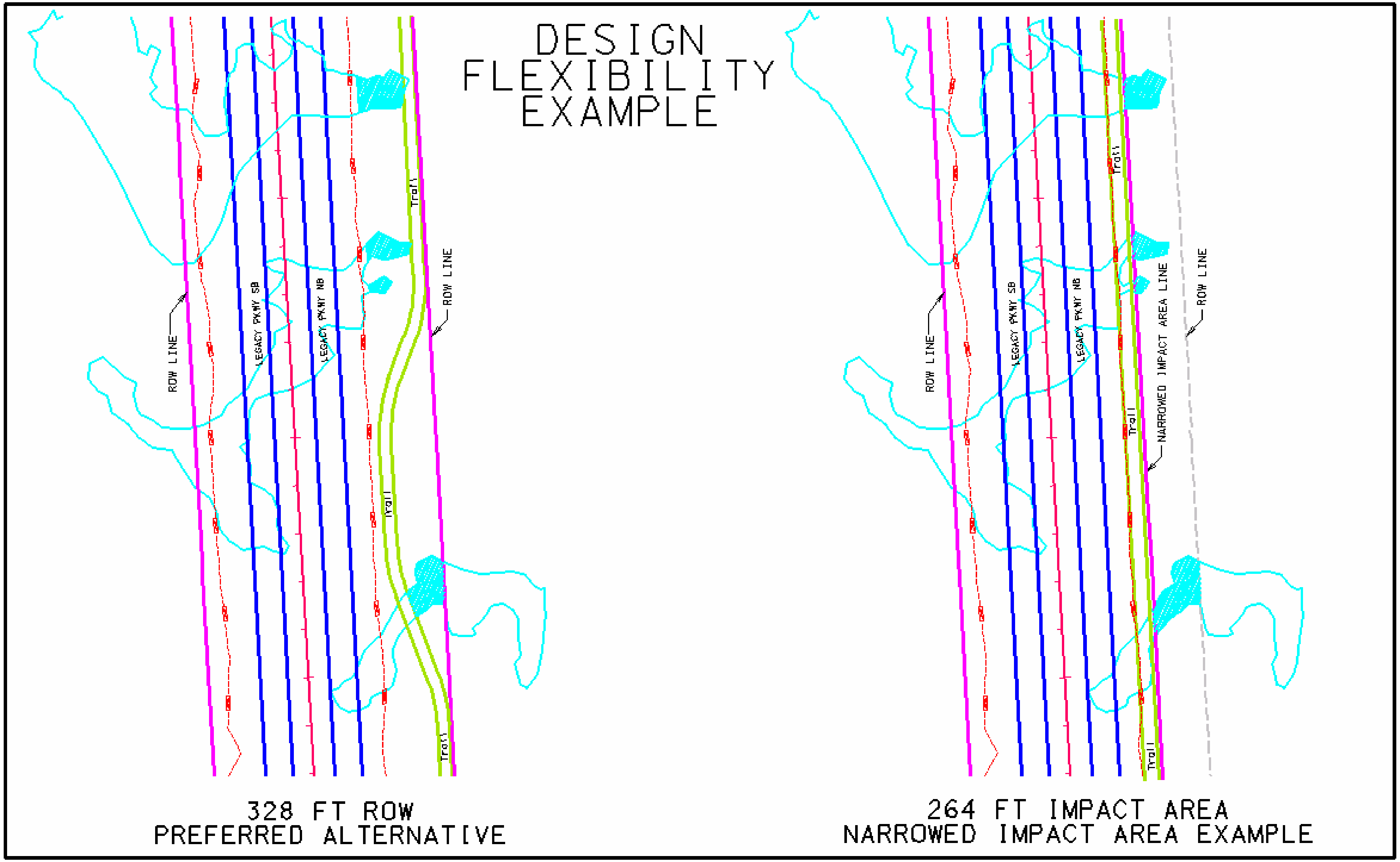

Figure 3-20. Design Flexibility Option 1

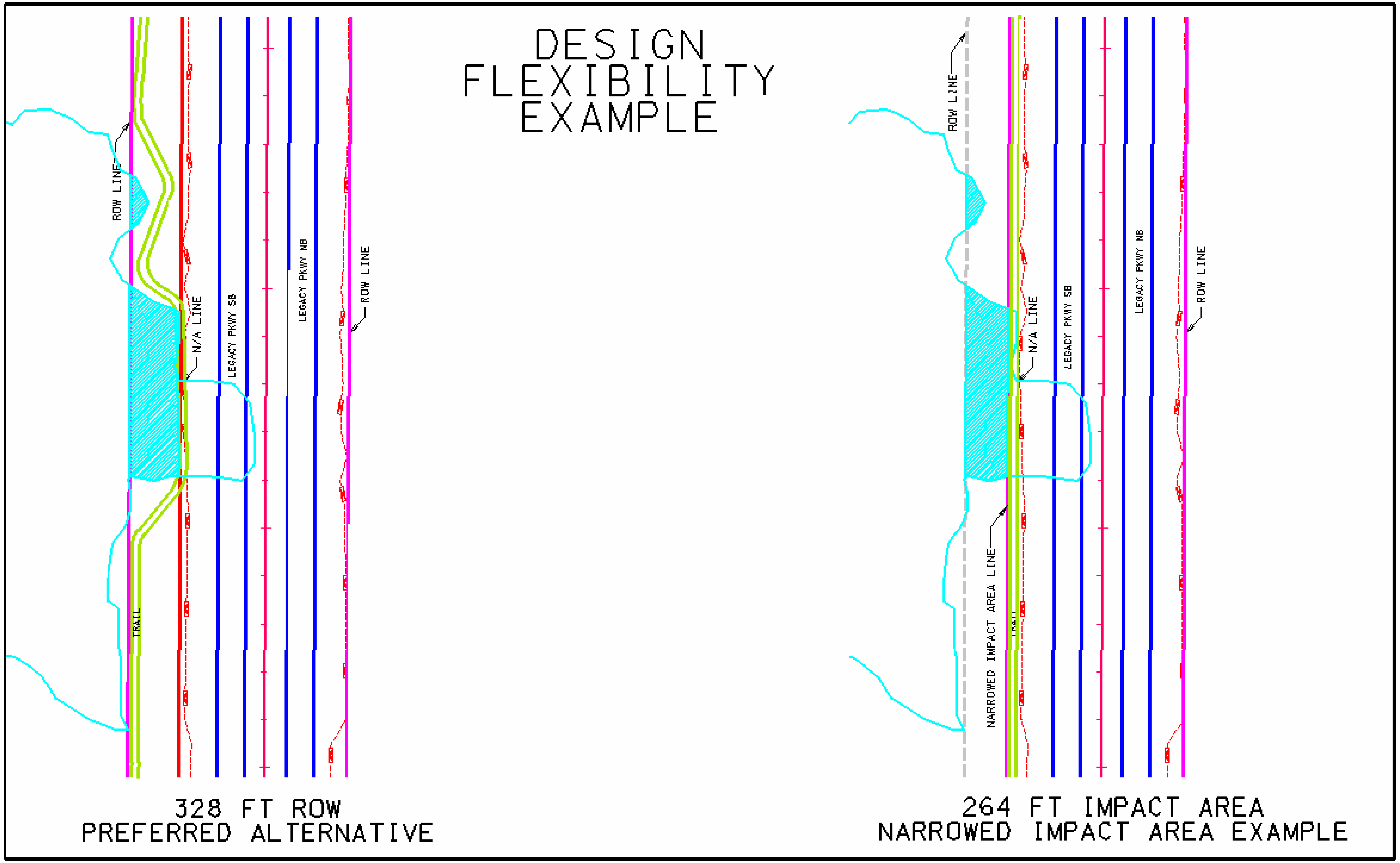

Figure 3-21. Design Flexibility Option 2

Summary

- The 404 permit assumed that all wetlands within the ROW would be impacted. The permit was originally issued based on the 100 m (328 ft) ROW, which is based on 114 acres of wetland impacts; the updated 95 m (312 ft) ROW reduces this to 113 acres of wetland impacts. In reality, the roadway footprint would impact fewer than 113 acres.
- When developing the final design for the Legacy Parkway Alternative E, the design-builder has been able to progress the design to avoid 14 acres of wetlands while still maintaining a roadway geometry that meets design and safety standards. Because the avoided wetlands are in the interchange areas, which are the same for each ROW width, the acreage of impacts to wetlands for each of the alternatives can be reduced by 14 acres.
- In addition, the final design would further reduce impacts by avoiding wetlands within the ROW as a result of the design flexibility described in Section 3.2.2, Design Flexibility. Using this cross-section could decrease wetland impacts by 1 to 2 acres.
- Based on work done before the injunction, Alternative E would impact about 99 acres of wetlands.
- Substantial adjustments to the dimensions of ROW components (such as median width) would result in relatively small changes in overall wetland impacts. For example, assuming that all wetlands within the ROW are impacted, reducing the ROW width from that of Alternative E at 95 m (312 ft) to 80 m (261 ft) by reducing the median to 8 m (26 ft) and buffer area to 3 m (10 ft) would reduce the total amount of impacted wetlands within the ROW by 3 acres. Table 3-3 below summarizes this relationship.

Table 3-3. Wetland Impacts for Alternative ROW Widths

ROW Option	ROW Width, m (ft)	ROW Area (acres)[a]	Wetlands within ROW (acres)[b]	Maximum Wetland Impacts (acres)[c]
Final EIS Preferred Alternative	100 m (328 ft)	925	114	100
Alternative E	95 m (312 ft)	900	113	99
Reduce median to 9 m (30 ft)	89 m (292 ft)	881	112	98
Reduce median to 8 m (26 ft)	87 m (285 ft)	880	112	98
Reduce median to 8 m (26 ft) and buffer area to 3 m (10 ft)	80 m (261 ft)	855	110	96
Reduce median to 8 m (26 ft) and eliminate trail and buffer area	71 m (234 ft)	825	106	92

[a] The ROW area includes interchanges.

[b] This column shows the total area of wetlands within the ROW.

[c] As discussed in Section 1.3, Background and Explanation of the Final EIS Preferred Alternative and Alternative E ROW Width, Footprint, and Related Wetland Impacts, 14 acres of wetland impacts identified by the design-builder will be avoided, and actual impacts would be less than the total area of wetlands due to design flexibility.

3.3 Median Width Considerations

This section presents information on the components of the median width.

The project's environmental documentation, including the FEIS, USACE and FHWA Records of Decision, and the 404(b)(1) Evaluation Report, all contain descriptions of the rationale for the proposed median width. These reasons include:

- Consistency with design standards and guidance
- Safety
- Water quality
- Visual quality
- Consistency with local land use and transportation plans
- Public preference for a parkway-type facility (based on input gathered through scoping and public involvement activities)

The following criteria were used in the analysis of median width presented in this Technical Memorandum:

- Consistency with UDOT design standards and nationwide guidelines (for example, AASHTO)
- Wetland impacts
- Safety
- Water quality impacts

The median is the area that separates the opposing travel lanes. For this Technical Memorandum, the median width is defined as the distance between the opposing travel lanes and includes the interior shoulders as illustrated in Figure 3-1 and Figure 3-2 on page 11.

As noted in Section 3.1.1, Cross-Section Right-of-Way Components, the proposed median width for the Legacy Parkway Alternative E ROW is specified by UDOT Standard Drawing DD 4. This median width is consistent with the guidelines of AASHTO's Green Book (2001) and AASHTO's *Roadside Design Guide* (2002), which together provide nationwide industry standards and guidance on the design and operation of roadways.

Additional information on ROW considerations in planning the Legacy Parkway project, including median width options, is presented in the following sections.

3.3.1 Future Travel Lanes

This Technical Memorandum reviews the information and analysis in the FEIS and the Records of Decision including the USACE 404(b)(1) evaluation concerning the question of possible future additional travel lanes within the Legacy Parkway ROW. The information has not changed since the FEIS or earlier federal decisions. UDOT does not plan to place additional lanes in the Legacy Parkway ROW.

USACE addressed this issue in its 404(b)(1) evaluation, even though the addition of lanes was not reasonably foreseeable. UDOT does not currently propose to or have future plans to add additional travel lanes to the Legacy Parkway. If additional lanes were proposed in the future, the impacts of this action would follow appropriate environmental requirements. The sequencing analysis performed for the Supplemental EIS concluded that a six-lane facility would not help reduce congestion between now and 2020.

3.3.2 Development of the Legacy Parkway Median

Research on median and safety issues supports the standards discussed in Section 3.1.1, Cross-Section Right-of-Way Components, which were used to design the Legacy Parkway. A survey of recent and relevant research was conducted to gather and analyze information on median characteristics and roadway operations for this Technical Memorandum. In addition, UDOT's safety records were reviewed to assess the relationships between medians and safety in Utah.

Research Related to Median Design Guidance

AASHTO and UDOT standards are based on transportation and engineering research and many years of professional experiences in the planning, design, and operation of roadways. Safety is and has historically been a primary consideration in the planning and design of transportation facilities.

Congress emphasized highway safety in the passage of the Highway Safety Act of 1966. Further, in July 1973, the House Committee on Public Works published the following mandate relating to highway safety:

> Whose responsibility is it to see that maximum safety is incorporated into our motor vehicle transportation system? On this, the subcommittee is adamant. It is the responsibility of Government and specifically those agencies that, by law, have been given that mandate. This responsibility begins with the Congress and flows through the Department of Transportation, its Federal Highway Administration, the State Highway Departments and safety agencies, and the street and highway units of counties, townships, cities, and towns. There is no retreating from this mandate in either letter or in spirit (AASHTO 1974).

This emphasis on safety is also demonstrated by FHWA's adoption of the AASHTO publications *Highway Design and Operational Practices Related to Highway Safety* (1974) and *Highway Safety Design and Operations Guide* (1997).

The Green Book provides guidance to the designer by referencing a recommended range of values for all highway critical dimensions including median width. This flexibility allows the designer to use best professional judgment in determining the appropriate highway critical dimensions in context of the project location and setting. The Green Book recommends that median widths on rural freeways should be between 15 to 30 m (50 to 100 ft). The 15 m (50 ft) median provides for 1.2 m (4 ft) shoulders and 1V:6H fore slopes with a 1.0 m (3 ft) median ditch and provides adequate space for vehicle recovery.

The Roadside Design Guide presents information on the latest state-of-the-practice in roadway safety. The findings of the RDG are based on current accident and research studies. The intent of the RDG is to present the concepts of roadway safety to the design engineer in such a way that the most practical, appropriate, and beneficial roadside design can be accomplished for each individual project.

- Median barriers should be installed only if the consequences of striking the barrier are expected to be less severe than if no barrier existed.
- Figure 6.1 of the RDG provides the designer with suggested guidelines when site-specific data are not available, as is the case for new facilities. The figure depicts barriers as optional between 9 and 15 m (30 and 50 ft) and barrier as not normally considered above 15 m (50 ft).

AASHTO's Green Book (2001) also refers to a study by S.R. Byinton, *Interstate System Accident Research* (Byinton 1963), which found a lower crash rate on four-lane divided (open-median) highways than on four-lane undivided (striped) highways. This conclusion is also supported by the recent accident data discussed in the following sections. Narrower medians with barriers can eliminate head-on collisions, but will increase same-direction crashes due to a smaller recovery space.

Research on Median Width and Safety

Highway Safety Information System

The most comprehensive recent study on the relationship between median width and highway safety was conducted using data from the Highway Safety Information System (HSIS). The HSIS provides a multi-state safety database that contains accident, roadway inventory, and traffic volume data for a select group of states, including Utah. This study, *The Association of Median Width and Highway Accident Rates* (FHWA 1993), which is provided as Appendix B, used these data to analyze the relationship between median width and highway accident rates. Accident rates are defined by the number of accidents per hundred million vehicle-miles traveled for a length of highway. This study used statistical analyses to define the relationship between median widths and accident rates in terms of the relative effects of changes in median width on accident rates (see Figure 3-22 below).

The study, which looked at open medians without a median barrier, assessed roadways in Utah and Illinois and found that the total accident rate appears to decline steadily as median width increases. The study also found that increasing median width reduced certain types of accidents by varying rates.

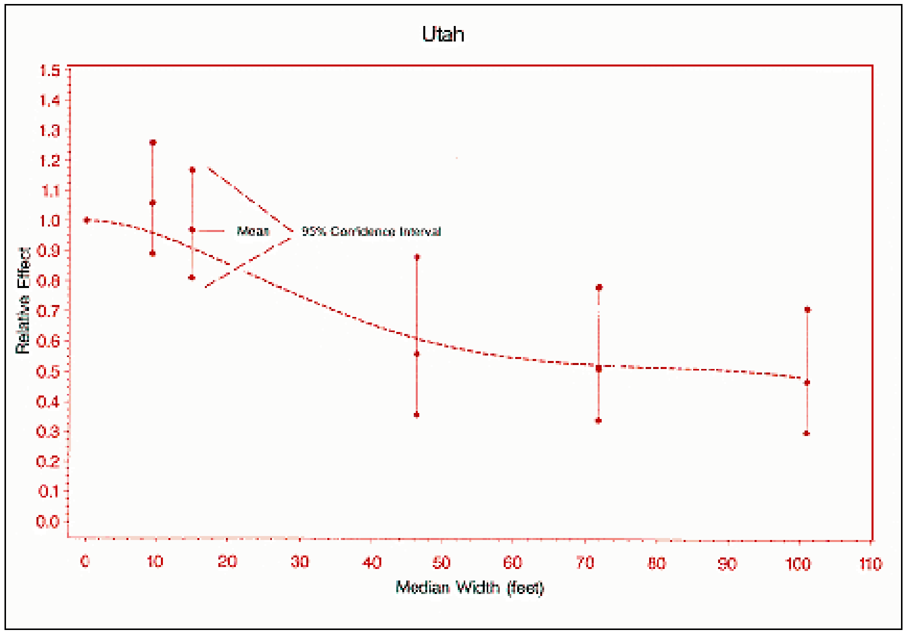

Figure 3-22. Relative Effects of Median Width on Total Accident Rate

Source: FHWA 1993

The results of the 1993 FHWA study show that "...the total accident rate appears to decline steadily with increasing median width." The study also mentions that medians that are 15 m (50 ft) wide are much safer than a narrower median. The study indicates that medians wider than 15 m (50 ft) appear to provide even greater safety benefits. The study remarked, "…in the design of new highways, our findings would support medians considerably wider than 30 to 40 ft (9.2 to 12.2 m)."

The findings of the study agree with the design guidelines provided in the AASHTO Green Book (2001). The study points out that it is difficult to summarize AASHTO guidelines for median width and the need for median barriers, since material is found in a variety of sections and the Green Book does not provide "hard" guidelines.

National Cooperative Highway Research Program

A recent study prepared for the National Cooperative Highway Research Program (NCHRP) reports findings on guidelines for median safety. This study, *Improved Guidelines for Median Safety* (NCHRP 2004), evaluated median safety using cross-section data, roadway inventory data, and data on crashes that involved medians. The study, provided as Appendix C, used the data to analyze the relationship between median width and highway accident rates.

This study points out that the AASHTO criteria for determining whether a median barrier is warranted have not changed for more than 30 years. The study was conducted to help develop improved guidelines for using median barriers and selecting median widths on newly constructed and reconstructed high-speed roadways.

The NCHRP study examines State Transportation Agency (STA) Median Barrier Warrant Criteria, which vary among STAs. STAs base their criteria either on safety-based studies or on economic evaluations. The following list gives examples of various STAs' median width and barrier requirements that demonstrate the variation in Median Barrier Warrant Criteria between different states.

- California conducted a study in 1968 and concluded that median barriers should be placed in medians up to 13.7 m (45 ft).
- New Hampshire and Washington install median barriers on medians less than 15 m (50 ft).
- North Carolina has revised its median design policy so that new freeways must have median widths of at least 21 m (70 ft). Any median narrower than 21 m (70 ft) requires a median barrier.

Though median width designs vary from state to state, they are based on safety studies indicating that medians narrower than 13.7 to 15 m (45 to 50 ft) are not safe without a barrier. One of the conclusions drawn from the NCHRP study is that increasing median widths on divided, limited-access highways decreases crash frequency. (The effects of median barriers are discussed in the section Research on Median Barriers and Safety below.)

Public Roads November/December 2003

The FHWA publication *Public Roads* featured an article on fatality rates on South Carolina's interstates (Zeits 2003). The article, "Low-Cost Solutions Yield Big Savings," examined South Carolina's approach to addressing median-related traffic fatalities. Based on the article, the South Carolina Department of Transportation (SCDOT) decided to install barriers on medians less than 18 m (60 ft). SCDOT determined that wider medians were safer than narrow medians. This is another example of how median width contributes to safety.

Summary

Using the information from these studies, UDOT selected a median width of 15 m (50 ft) based on safety and professional judgment. This median width is also within the recommended AASHTO range. Refer to Appendix B and C to review the studies and findings related to median width, accident rates, and improved guidelines.

Research on Median Barriers and Safety

Utah Accident Data. Table 3-4 presents accident data collected on existing freeway systems in Utah (Interstates 15, 215, 70, and 80). Data from the UDOT Maintenance Division database and the UDOT roadway photo log were reviewed, and a visual inspection of the urban freeways in the Salt Lake area was performed to determine the locations of concrete barrier medians. The accident reports described the accident type, number of vehicles involved, accident severity, object struck, collision type, and date, as well as other accident information.

Table 3-4. Utah Accident Data

Description	Cross-Section Geometry	Accident Rate per Million VMT					
		1997	1998	1999	2000	2001	Average
Total Accidents	4+ lanes, barrier median	1.30	1.18	1.14	1.40	1.45	1.29
	4+ lanes, open median	0.68	0.70	0.65	0.67	0.63	0.67
Median-Related Accidents	4+ lanes, barrier median	0.11	0.05	0.05	0.05	0.07	0.07
	4+ lanes, open median	0.01	0.01	0.01	0.01	0.01	0.01

Table 3-4 presents accident rates for highway segments with and without median barriers. An open median is a median greater than 12 m (40 ft) without a barrier. The findings of this study indicate that the average total accident rate (1997–2001) is 1.29 accidents per million vehicle-miles traveled (VMT) for roadway sections with a barrier and 0.67 accidents per million VMT for sections without a barrier.

Crossover accidents were also reviewed and included in the overall accident rate. These accidents occurred when a vehicle traveled through the median and hit a vehicle or vehicles traveling in the opposite direction. These accidents often involved injuries and/or fatalities.

New Jersey Accident Data. Data from New Jersey interstate and state highways that relate road cross-sectional geometry to accident rates provide a useful comparison with the Utah accident data presented above. These data were used because they were readily available through literature searches, presented accident data in a similar format, and were from the same period. The New Jersey data are presented in Table 3-5 below.

Table 3-5. New Jersey Accident Data

Cross-Section Geometry	Accident Rate per Million VMT				
	1997	1998	1999	2000	Average
4+ lanes, barrier median	2.21	1.95	1.89	2.24	2.07
4+ lanes, open median	1.66	1.43	1.48	1.73	1.58

Source: New Jersey Department of Transportation 2003

While the overall accident rates are substantially higher for the New Jersey data, the roadway sections with the open median have the lowest accident rate of the various cross-sections documented. The average accident rate for the open median section was 1.58 accidents per million VMT for 1997–2000. The average accident rate for a cross-section with a barrier median for the same period was 2.07.

Determination of Median Characteristics for the Legacy Parkway

Safety is a primary planning and design consideration for determining median width and whether median barriers are warranted for roadways. Regarding medians, the *Roadside Design Guide* notes that "...a roadside free of fixed objects with stable, flattened slopes enhances the opportunity for reducing accident severity" (AASHTO 2002). The *Roadside Design Guide* cites 15 m (50 ft) as the width for evaluating the need for a barrier for a highway with operational and geometric characteristics like those of the Legacy Parkway (a high-speed, controlled-access roadway with an average daily traffic greater than 20,000 vehicles per day).

The *Roadside Design Guide* allows the state transportation agencies to determine the minimum width for an open median for which median barrier must be used. State transportation agencies base their standards on safety, traffic volumes, speed, and local knowledge of the area. In other words, a median narrower than 15 m (50 ft) could require a median barrier (AASHTO 2002). Using the information from the studies mentioned above, UDOT specifies a 15 m (50 ft) median width for the proposed Legacy Parkway.

In general, the greater the separation of travel directions, the more safely the roadway will operate. For the Legacy Parkway, the proposed separation of the travel lanes by 15 m (50 ft) is intended to provide safe separation (without a barrier) of the traffic, an adequate vehicle recovery area consistent with UDOT standards, and a median width within AASHTO's recommended range. This is UDOT's desirable width based on safety and other reasons such as drainage.

Safe separation and adequate recovery areas reduce cross-median collisions, which tend to be significantly more severe than other types of accidents.

AASHTO's Green Book notes that medians of 15 to 30 m (50 to 100 ft) are typical for facilities like the proposed Legacy Parkway. The Green Book further states that a median width of 23 to 30 m (75 to 100 ft) is preferred for minimizing the number of crossover collisions (AASHTO 2001, p. 103).

The 15 m (50 ft) median proposed for the Legacy Parkway is at the minimum of the Green Book's range of widths for open medians. Reducing the median width from 15 to 8 m (50 to 26 ft) would reduce wetland impacts by about 1 acre, but it is likely to increase the accident rate based on the referenced studies.

A barrier is not *required* for the Legacy Parkway median as proposed. The Legacy Parkway's open median is intended to provide safe separation of the opposing travel lanes without a median barrier. In this case, given the 15 m (50 ft) median, a median barrier would be warranted only if the consequences of striking the barrier were less severe than if no barrier existed (AASHTO 2002, p. 6-1). The *Roadside Design Guide* indicates that a median barrier would need to be evaluated for a highway like the Legacy Parkway if the median were 15 m (50 ft) or narrower.

Several barrier options are available and approved for use in medians. AASHTO's *Roadside Design Guide* approves the use of the following median barriers, which are classified as flexible, semi-rigid, or rigid systems:

- **Three-Strand Cable.** The Three-Strand Cable barrier, a flexible system, needs to allow for 3.6 m (12 ft) of deflection. The cable barrier is less expensive to install, but after a hit it cannot redirect another hit until it is repaired. It is also more labor-intensive to repair.
- **Box-Beam.** The Box-Beam barrier, another flexible design, requires 1.7 m (5.5 ft) of design deflection.
- **Blocked-Out W-Beam.** The Blocked-Out W-Beam is a semi-rigid system that requires only 1.2 m (4 ft) for deflection, which is less than the flexible systems.
- **Blocked-Out Thrie Beam.** The Blocked-Out Thrie Beam system, another semi-rigid design, requires 0.9 m (3 ft) of deflection.
- **Concrete Median.** The only rigid system available is the Concrete Median barrier. With a rigid system there is no deflection, so it allows the narrowest median. The concrete barrier was selected for this analysis because it does not deflect and allows the narrowest median possible.

Replacing the proposed Legacy Parkway 15 m (50 ft) open median with two 3.6 m (12 ft) interior shoulders and a 0.6 m (2 ft) barrier would reduce the ROW requirements by 8 m (27 ft). This would reduce wetland fill by 1 acre.

Summary

- The proposed median width for the Legacy Parkway Alternative E ROW (15 m, or 50 ft) is consistent with UDOT design standards and is at the minimum range of national guidelines.
- Research on median safety supports a median width of 15 m (50 ft) or greater for new facilities.
- UDOT does not intend to use the median for future travel lanes, and the median width was not determined with future travel lanes as a consideration.
- Median width is based largely on safety factors. Based on the above studies, accident rates decrease as median width increases and vice versa.
- Using a median barrier can reduce the median width. However, median barriers generally increase overall accident rates compared to open medians and would not provide water quality control benefits (see Section 3.3.3, Medians and Water Quality Treatment).
- AASHTO's Green Book recommends that medians of less than 15 m (50 ft) be evaluated to determine the need for barriers.

3.3.3 Medians and Water Quality Treatment

This section reviews the project team's consideration of water quality treatment options. UDOT's updated standard using a 15 m (50 ft) median, instead of the 20 m (66 ft) median in the FEIS, still provides enough room to meet the required water quality standards. Therefore, no additional water quality treatment measures will be needed due to the change in median width.

Proposed Water Quality Treatment Method

A primary objective of planning stormwater quality management for the Legacy Parkway was to eliminate concentrated stormwater discharges to the extent feasible. This approach was determined in coordination with the Utah Department of Environmental Quality (UDEQ) in a meeting held on November 4, 1999. UDOT and UDEQ negotiated and determined that point discharges need to be eliminated wherever feasible to meet the water quality standards set for the Legacy Parkway. Eliminating point discharges would have positive effects on turbidity and removal of suspended solids. Point discharges contribute to channel erosion and channel instability. Point discharges can also adversely impact surrounding resources and the existing ecosystem. The proposed water quality treatment methods of grassed medians and vegetated side slopes were selected because they provided the most benefit due to the proximity of the area wetlands.

UDEQ held a public hearing on February 18, 1999, regarding the 401 Water Quality Certification application for the Legacy Parkway. A new application was submitted, and a second hearing was held on October 3, 2000. The new application was submitted due to the change of the Preferred Alternative from the DEIS to the FEIS. UDEQ responded to comments received at the October 3 public hearing by preparing a Response to Comments document (Moellmer 2000), and the 401 Water Quality Certification was issued for the Legacy Parkway.

In the Water Quality Certification letter sent to USACE in 2000, UDEQ's Division of Water Quality made the following statement regarding the 401 Water Quality Certification Application for the Legacy Parkway:

> We [UDEQ] have reviewed the referenced application. It is our opinion that applicable water quality standards will not be violated if appropriate BMPs [best management practices] are incorporated to minimize the erosion-sediment load to any adjacent waters. In addition, a storm water discharge permit administered by this office will regulate the construction of this project, and construction activities must be controlled to meet requirements of that permit.
>
> Pursuant to Section 401(a)(1) of the Federal Water Pollution Control Act, as amended in 1987, it is herby certified that any discharge resultant from the project will comply with applicable State Water Quality Standards…(Ostler 2000).

The FHWA report *Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff* recommends: "...grassed waterways should be used to collect and transport highway runoff where practical" (FHWA 1988). Research conducted on water quality Best Management Practices (BMPs) available to treat highway runoff supports the use of vegetated buffer strips and swales for highway facilities. A study by the Center for Research in Water Resources at the University of Texas came to the following conclusion:

> Include vegetated buffer strips or grassed swales in the design of new highways or renovation of old highways. Vegetated BMPs are especially beneficial in environmentally sensitive watersheds or recharge zones; in addition, they could be used when regulations require enhancement of highway runoff water quality (FHWA 1996).

The researchers recommend that sheet flow be maintained to allow better treatment. Treating water within the ROW is beneficial for any areas outside the parkway ROW, since this method allows adequate treatment of stormwater runoff to meet the permit requirements for discharge before leaving the ROW.

The USACE's 404(b)(1) Evaluation Report stipulates that all drainage associated with the Legacy Parkway should be detained as it flows through the grassy area of the median. This removes suspended solids and some dissolved pollutants through filtration, adsorption to sediment and organic particles, and infiltration. An 80% total suspended solids (TSS) removal must be achieved to meet numeric water quality standards established by UDEQ (2000). A study was performed to determine the 80% TSS removal requirement (HDR 1999).

The particulate fraction (the percentage of a pollutant in solid form or bound to solid particles), compared to the dissolved form, constitutes the major component of most pollutants of interest in highway runoff (FHWA 1988). The 80% TSS removal also provides adequate reduction in heavy metal concentrations in highway stormwater runoff to ensure that numeric water quality standards are not exceeded. Due to their toxic effects on aquatic wildlife, heavy metals (primarily copper, lead, and zinc) are the pollutants of greatest concern with respect to highway stormwater runoff. The 80% TSS removal standard is higher than the regular water quality standards set by the UDEQ to help reduce the impacts to the surrounding Great Salt Lake ecosystem.

The degree of water quality improvement is a function of the length of time that stormwater is in the treatment system. For grassed swales and overland flow, the treatment is a function of detention (or travel) time of the runoff. Figure 3-23 shows TSS removal as a function of detention time for overland flow. The required 80% TSS removal is achieved with a 10-minute detention time.

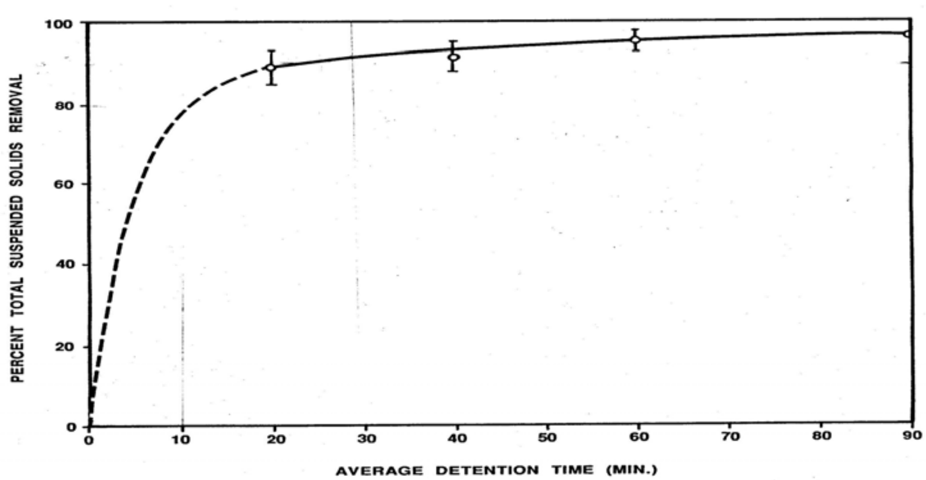

Figure 3-23. TSS Removal versus Detention Time for Overland Flow

Source: FHWA 1988

Grassed medians provide water quality treatment in two ways. First, stormwater quality is improved by traveling in sheet flow in a direction perpendicular to the highway, over the vegetated side slopes of the median. Assuming a 1:6 median side slope for the 15 m (50 ft) median, water travels and is retained for about 3 minutes before it reaches the center of the median. Second, by allowing stormwater to flow in the median for an additional 15 m (50 ft) parallel to the roadway, the water travels and is retained for an additional 10 minutes and the subsequent 80% TSS removal is achieved.

Where the side slopes from the two sides of the highway join, the median could be considered a grassed channel. Figure 3-24 shows the percent TSS removal as a function of channel length. The Legacy Parkway design incorporates catch basins every 100 m (328 ft) along the centerline of the median. Using Figure 3-24 and assuming half the spacing (50 m, or 164 ft) as the channel length, a grassed channel median would provide over 80% TSS removal. Because of the relatively flat side slopes of the median (1:6), the depth of water flowing in the channel would be very shallow, and runoff could be considered sheet flow for much of the channel's length.

In summary, a 15 m (50 ft) median adequately provides for 80% TSS removal when considering expected detention time and channel length. A narrower median might achieve an 80% TSS removal, but would affect the safety of the facility.

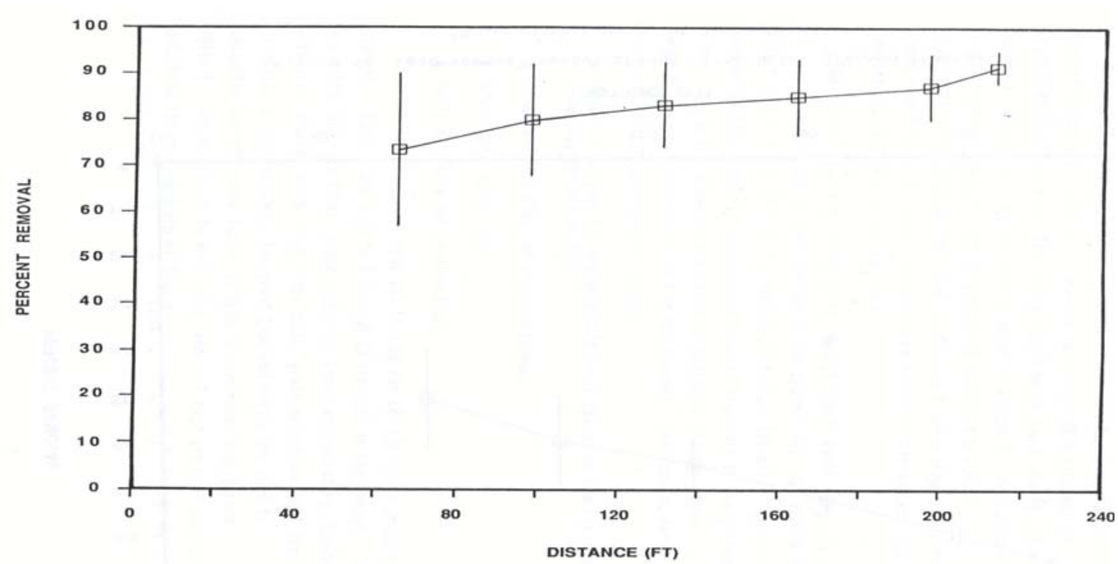

Figure 3-24. TSS Removal versus Channel Length for Grassed Channels

Source: FHWA 1988

Alternate Water Quality Treatment Considerations

All runoff from the Legacy Parkway must be treated to achieve water quality standards before it leaves the ROW. Overland flow treated through vegetated areas and swales was the preferable method for the Legacy Parkway as described above.

The following sections discuss alternate water quality treatment methods: detention basins, retention basins, and sediment traps and basins.

Detention Basins

Where alternate treatment methods are necessary, wet detention basins are the most readily adaptable and cost-effective management measure (FHWA 1996). Detention basins would be a potential alternative water quality treatment method. Detention basins are typically used to reduce the peak discharge from impervious areas (that is, to provide water *quantity* control). Detention basins are used so that receiving water bodies do not experience a sudden increase in flood flow rates due to stormwater runoff. If designed to improve water *quality*, detention basins can also be considered structural BMPs that allow suspended particles (TSS) to settle out of stormwater.

UDOT standards require that oil/gas skimmers be installed wherever detention basins are used. However, oil/gas skimmers were eliminated as a stand-alone alternate water quality treatment method. These devices remove only floating debris, oil, and other petroleum products and would not reduce TSS or heavy metal concentrations to levels that would meet the numeric water quality standards for receiving waters.

Area Required for Detention Basins

With the elimination of the median, all runoff that was previously treated by the grassed median would need to be routed to detention ponds. In the analysis that follows, the assumption is made that detention basins would be needed to treat stormwater from the inside shoulders and curving segments of the Legacy Parkway that are superelevated. The total area requiring treatment with detention basins is about 44 acres. The overland flow through the vegetated side slopes and existing ground on the outside edges of the roadway would provide the required water quality treatment for the remaining portions of the highway. To ensure that numeric water quality standards are not exceeded, detention basins would need to achieve 80% TSS removal.

The high groundwater table in the area of the Legacy Parkway restricts the depth of any detention basin, since a detention basin must be located above the groundwater table to operate properly. With this restriction, the depth of detention basins for the Legacy Parkway project would be limited to 1 m (3 ft).

Also, placement of the detention basins was evaluated. Detention basins could be placed either east or west of the proposed roadway, although stormwater would eventually have to be discharged to the west, into the Great Salt Lake. Along the project alignment, the topography is very flat, making it difficult to achieve the fall necessary to convey stormwater. This would pose a particular challenge if detention basins were located on the east side of the proposed alignment; the time required to convey water from west to east to west again (the natural fall, or grade, is to the west towards the Great Salt Lake) would be considerable, and the outlet channel or pipe would need to be deep or very flat (requiring a larger pipe or wider channel). These technical and logistical difficulties would require that the detention basins be placed along the west side of the proposed roadway.

Figure 3-25 shows the pollutant removal efficiency of detention basins as a function of the V_B/V_R ratio, where V_R is the volume of runoff and V_B is the required volume of a detention basin. Assuming a height (H) of 1 m (3 ft), an 80% TSS removal results in a V_B/V_R ratio of about 2.3. In other words, to achieve a TSS removal efficiency of 80%, the volume of detention should be 2.3 times the volume of runoff.

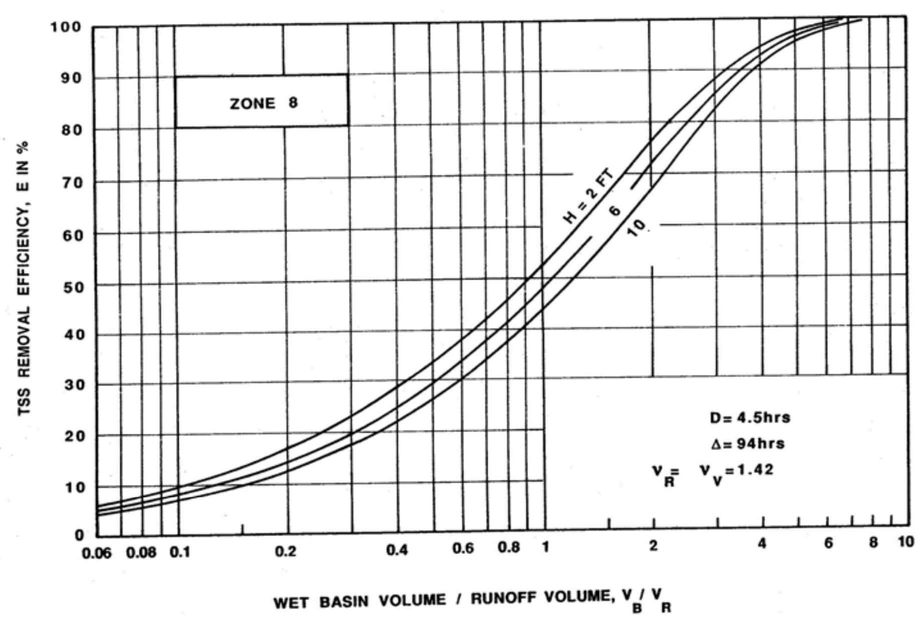

Figure 3-25. TSS Removal versus V_B/V_R Ratio

Source: FHWA 1988

Based on estimates of runoff quantities and detention time needed to meet pollutant removal requirements, about 18 acres would be required for detention ponds to adequately treat highway stormwater runoff from the proposed Legacy Parkway. This acreage was calculated using a 50-year design storm, which results in a runoff volume of 23.6 acre-feet. Assuming a 1 m (3 ft) maximum depth and a V_B/V_R ratio of 2.3, the required detention basin area would be 18.1 acres.

Equation 1

$$\text{Required Detention Basin Area} = \frac{(\text{Runoff Volume}) \times (V_B / V_R)}{\text{Depth of Detention}}$$

Equation 2

$$\text{Required Detention Basin Area} = \frac{(23.6\ \text{acre-feet}) \times (2.3)}{3\ \text{feet}} = 18.1\ \text{acres}$$

Detention basins require extensive piping and/or ditchwork to collect and convey stormwater runoff. The exact locations and sizing of specific collection systems and detention basins were not determined for this analysis. However, it was assumed that a detention basin would be placed every 305 m (1,000 ft). The entire length of the project, not including interchanges, is 13,800 m (45,280 ft). Placing a detention basin every 305 m (1,000 ft) results in about 45 basins.

To maintain gravity flow, detention basins are typically placed in low-lying areas. For this reason, it may be difficult to avoid wetlands. However, wetlands commonly occupy the same low-lying areas. With the depth restriction of 1 m (3 ft) and the required detention amount of 18.1 acres, the resulting basins would be about 0.4 acre each.

Equation 3

$$\frac{18.1\ \text{acres}}{45\ \text{basins}} = 0.40\ \text{acre}$$

A simple calculation to estimate the potential for detention basins to impact wetlands is shown in Equation 4.

Equation 4

$$\frac{\text{Wetlands Within ROW (acres)}}{\text{ROW (acres)}} = \%\ \text{ROW in Wetlands}$$

Equation 5

$$\frac{113\ (\text{acres})}{900\ (\text{acres})} = 13\%$$

Equation 6

$$\text{Detention Basin Area} \times \% \text{ ROW in Wetlands} = \text{Acreage of Wetland Impacts from Detention}$$

Equation 7

$$18.1(\text{acres}) \times 13\% = 2 \text{ acres}$$

These calculations indicate that there could be up to 2 acres of wetland impacts from the detention basins. If these impacts occurred, they would offset nearly all of the savings in wetland impacts from reducing the median width.

Retention Basins

Retention basins could also be used to handle stormwater runoff. Retention basins are ponds that do not discharge any stormwater to surrounding areas. Retention basins would retain all highway stormwater runoff and therefore all runoff pollutants. Due to retaining all the water with no discharge, these ponds would require even more area than detention basins and would have a greater potential to impact wetlands.

Sediment Traps and Basins

Sediment traps and basins also can be used to treat stormwater runoff. Sediment traps and basins function like a detention basin. They detain water for a significant time to allow the sediment to settle before the water is discharged. These basins also require additional area, similar to a detention basin, to treat stormwater runoff, and could impact additional wetlands and offset nearly all of the savings from reducing the median. These basins trap sediment, but would not achieve the 80% TSS removal required, so they are not a viable water quality treatment option.

Impacts of Concentrating Flows on the Hydrology of the Great Salt Lake Ecosystem

The Great Salt Lake ecosystem west of the proposed Legacy Parkway is a flat to undulating area consisting of grassed uplands, wetland depressions, and salt playas. Salt efflorescences (crusts) are common in the area, reflecting a lack of surface flows from snowmelt or rainfall. These unique conditions have led to the formation of habitat as discussed in Section 4.13 of the FEIS.

Detention basins would require constructing a drainage facility to transfer runoff to area streams or the Great Salt Lake. The flat nature of the land west of the Legacy Parkway alignment would require building open channels or drainage ditches instead of pipelines. Several historical drainage channels have been built through this area by the early pioneers, county flood control projects, and the cities. The impacts of these historical channels can be easily observed and typically include:

- Increased removal of surface water from areas surrounding the channels
- Lower groundwater table near the channels
- Expansion of invasive plant species along the channels

These impacts are discussed individually below.

Increased Removal of Surface Water

The existing constructed channels in the area passed through numerous depressions and resulted in leveling or grading of some of the surrounding land. This has provided a surface water drain that removes the water from depressed areas during snowmelt and rainfall. These depressions are a primary source of water for the grass meadows, salt playas, and even some of the emergent wetlands within the area for large portions of the early season. This is one type of wetland that was mandated to be mitigated by the 404 permit and included in the Legacy Nature Preserve Mitigation Plan.

One mitigation approach being taken in the Legacy Nature Preserve is to remove (fill in) existing drainage channels. In addition, the drainage design for the Legacy Parkway uses overland flow to the extent practical to avoid the need for concentrating flows and constructing drainage channels.

Lower Groundwater Table

The shallow groundwater near the Legacy Parkway is a source of water to several of the playa wetlands, emergent wetlands associated with shallow springs, and many of the uplands. With the groundwater table in most of the project area being only a couple feet below ground level, the existing stormwater drain channels also act as groundwater drains. These groundwater drains typically dewater areas ranging from 9 to 30 m (30 to 100 ft) on each side of the channel, lowering the groundwater table to approximately the bottom of the channel. Any newly constructed channels could increase impacts to the wetlands in the areas around these channels.

Expansion of Invasive Species

Wherever stormwater outfall channels have been constructed, invasive species such as Russian olive, phragmite, salt cedar, and non-native grasses, weeds, and other plants have quickly become established. These invasions occur because construction disturbances change the area’s hydrologic characteristics. These species have a potential to dislodge several of the native species in the Great Salt Lake ecosystem. These invasive species are a major management issue for the Legacy Nature Preserve, which is dedicated to the preservation of the Great Salt Lake ecosystem.

Based on these observed impacts from existing open-channel drainage systems, constructing open channels to convey the concentrated flows across areas west of the Legacy Parkway including the Legacy Nature Preserve is undesirable. As a result, the 401 water quality certification and 404 permit requirements for the Legacy Parkway drainage system require the use of BMPs that prevent concentrating stormwater discharges and maintain existing hydrologic flow characteristics to the extent practical.

Summary

Water quality treatment considerations with respect to median width are summarized in Table 3-6.

Table 3-6. Summary of Different Water Quality Treatment Methods and Associated Impacts

Evaluation Factors	Grassed Median, 95 m (312 ft) ROW	Detention Basins, 87 m (285 ft) ROW	Retention Basins, 87 m (285 ft) ROW
Total land required	900 acres (ROW)	880 acres (ROW) + 18.1 additional acres (detention) = 898.1 acres	880 acres (ROW) + more than 18.1 acres (retention) = more than 898.1 acres
Average treatment efficiency	80%	80%	100%
Wetland impacts	99 acres with no additional impacts.	98 acres with 2 potential additional acres of impact to construct detention basins. Additional indirect impacts to convey stormwater discharge through wetland areas. (Total wetland impacts = 100 acres.)	98 acres with at least 2 potential additional acres of impact to construct retention basins. (Total wetland impacts = more than 100 acres.)
Hydraulic system	Sheet flow	Concentrated discharges	No discharge

3.4 Berm/Buffer Area, Trail, and Utility Corridor Considerations

This section presents information on buffer width.

For the purposes of this evaluation and discussion, it is important to clarify the concept of the buffer area. This area provides a buffer between the trail[8] and the roadway's clear zone outside the travel lanes (see Figure 3-1, FEIS Preferred Alternative Cross-Section with Berm, on page 11). As such, the area is more appropriately referred to as a buffer area, rather than a berm or future utility corridor (as it is referred to in previous documentation). This area is not intended to serve as a future utility corridor (see Section 3.4.4, Future Utility Corridor Considerations).

The buffer area between the clear zone and the trail is proposed for the full length of Alternative E (and all build alternatives). Along the 5.1 km (3.2 mi) where the berm is proposed, the buffer is 26 m (84 ft) wide and the trail is 5 m (17 ft) wide. The berm is proposed on the east side of Alternative E between 500 South and Porter Lane and along the west side between Glover's Lane and State Street. Where there is no berm, the buffer is 25 m (81 ft) wide. However, where there is no berm within the buffer area, the trail width is 6 m (20 ft) due to fill for the trail. The width of the trail (for the portions with and without the berm) is based on AASHTO guidelines for multiple use trails. The ROW width is the same whether or not there is a berm.

The proposed buffer area fulfills the following functions:

- It provides safe separation between the roadway and the trail.
- It provides a visual and acoustic buffer between the Legacy Parkway and the adjacent trail and land uses.

[8] The width of the trail (for the portions with and without the berm) is based on AASHTO guidelines for multiple-use trails.

3.4.1 Safe Separation between Roadway and Trail

The buffer area and berm serve key functions related to the parkway and the trail. Most importantly, the buffer area provides a safe separation between the roadway clear zone and the multi-use and equestrian trails. Regarding the design of trails adjacent to highways, AASHTO's *Guide for the Development of Bicycle Facilities* notes:

> When two-way shared use paths are located adjacent to a roadway, wide separation between a shared-use path and the adjacent highway is desirable to demonstrate to both the bicyclist and motorist that the path functions as an independent facility for bicyclists and others (AASHTO 1999).

A "wide separation" is not defined in the Guide. Similarly, UDOT does not have design standards or guidelines for separating trails from adjacent highways. A review of design standards and guidance from other state departments of transportation revealed that other states do not have such standards or guidance either.

UDOT developed an 80 m (264 ft) cross-section with a reduced buffer area for use in areas where the facility crosses environmental resources but where there is no berm or interchanges. This is the cross-section described in Section 3.2.2, Design Flexibility. This cross-section reduces the ROW by 15 m (48 ft) by reducing the buffer to 11 m (36 ft) (see Figure 3-26). Wetland impacts could potentially be reduced by about 1 to 2 acres. This section places the trail at the minimum distance from the roadway, at the toe of slope, while still meeting UDOT design standards.

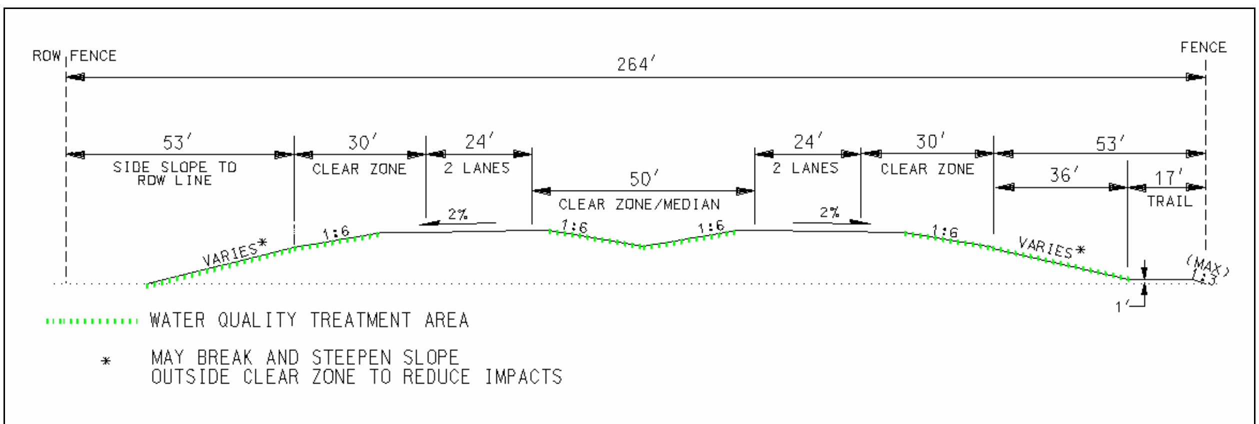

Figure 3-26. Alternative Cross-Section with Open Median and Reduced Buffer

Due to the trail's dimensions and trail design standards, the trail can meander around wetland resources to a much greater extent than a roadway can. If the buffer area is greatly reduced, there will also be much less flexibility to avoid wetland resources within the ROW.

As noted in Section 3.1.1, Cross-Section Right-of-Way Components, the dimensions of the buffer area where the berm is located are based on the height of the berm (3 m, or 9 ft) and the UDOT standards for non-roadway side slopes. The buffer width was kept consistent throughout the length of the Legacy Parkway.

3.4.2 Visual and Acoustic Buffering

Visual and acoustic buffering provided by the buffer area is important to the multi-modal use of the trail. The trail provides a pedestrian/bicycle path with a parallel equestrian path. The trail users' experiences would be enhanced by a greater distance from and less noise due to the parkway and its traffic. Throughout the planning process for the Legacy Parkway, the surrounding communities have expressed their preference for the landscaped buffer area to separate the trail from the roadway.

As noted above, the berm is proposed only in those areas where adjacent land uses require greater visual and acoustic buffering than that provided by the separation from the Legacy Parkway. Public comments received through the project's public involvement activities demonstrated a preference for an earthen berm as a more natural visual and acoustic barrier rather than a common noise wall. Section 2.2.1 in the FEIS discussed the selected locations of the berm to provide buffering to the adjacent communities.

3.4.3 Support from the Local Cities

In a meeting held with the City of Farmington in July 2003, city representatives made the following statement regarding the berm:

> Farmington is very aesthetically minded and prefers the landscaped berm for noise mitigation to noise walls. The City would not accept a UDOT standard noise wall (UDOT 2003a).

A meeting was held with the City of West Bountiful on July 10, 2003. They had the following concerns regarding the berm:

> The landscaped berm is very important to the City. West Bountiful conceded to the Legacy Final EIS Preferred Alternative because they were going to get a landscaped berm and trail facilities adjacent to the residential areas. This was considered mitigation for impacts (UDOT 2003b).

On July 10, 2003, a meeting was held with the City of Woods Cross. The City provided the following information regarding the berm:

> Woods Cross supports the trail system provided with the Final EIS Preferred Alternative and the City has tied its trail system into Legacy. It would be a shame to trade the Legacy Parkway with its trail/berm for a ribbon of concrete through a community. Gary Uresk, City Administrator, spoke to the transportation funding mechanisms designed to make transportation facilities a benefit to communities, therefore amenities need to be included (UDOT 2003c).

As noted previously, the trail facilities are integral to the purpose and need for a "parkway" facility. Section 3.7 in the FEIS provides information that was gathered from each community relating to the trail facilities.

3.4.4 Future Utility Corridor Considerations

Regarding the issue of the utility corridor, Figure 2-9 of the FEIS shows the cross-section of the Legacy Parkway with and without the berm and contains a note showing the location of a "potential future utility corridor." There is no utility corridor proposed or planned as part of the project, and the dimensions of the buffer area were not affected by the potential for placing utilities in the ROW in the future. The Jordan Valley Water Conservancy District and the Weber Basin Water Conservancy District have identified a 40-mile pipeline in their long-range plan (to be completed in 15 to 20 years). However, because no proposal or formal request has been submitted, this pipeline is not considered to be part of the Legacy Parkway project. This issue is discussed at length in the Responses to Comments in the FEIS (Letter 842, comments 201 and 206). If a utility corridor were proposed in the future, the impacts of this action would be fully analyzed.

3.4.5 Summary

- The proposed buffer area provides a safe separation between the Legacy Parkway roadway and the trail.
- Reducing the cross-section to 80 m (264 ft) would reduce wetland impacts by about 1 to 2 acres.
- Public comments expressed support for the landscaped buffer and berm. The surrounding communities support a parkway facility that include a berm and trail.
- The buffer area provides visual and acoustic buffering for adjacent land uses. The berm and buffer landscaping will provide a "parkway" element to the facility.

3.5 Summary of Alternative ROW Widths

Several issues were raised with respect to the median and the berm/buffer components of the ROW. This Technical Memorandum examines whether a narrower median is practicable and whether a ROW without a berm is practicable. Since the FEIS, UDOT has changed its standard drawing for facilities like the Legacy Parkway, and the proposed ROW width is 5 m (16 ft) narrower than the ROW in the FEIS.

Several alternative scenarios (not presented in the FEIS) with respect to median widths and the buffer area have been developed. UDOT developed two cross-sections with medians narrower than the proposed 15 m (50 ft) median.

- One section has an 8 m (26 ft) median with interior shoulders, a concrete median barrier (consistent with AASHTO guidelines), and the originally proposed berm/buffer and trail area (25 m, or 81 ft). This is the 87 m (285 ft) cross-section.
- The other section has an 8 m (26 ft) median with interior shoulders, a concrete median barrier, a berm/buffer area reduced to 3 m (10 ft), and a trail. This is the 80 m (261 ft) cross-section.

These alternatives were compared to Alternative E (with a 95 m [312 ft] ROW). For the purposes of this analysis, the alternative ROW sections were narrowed on the existing centerline.

Table 3-7 below compares Alternative E with the 87 m (285 ft) and 80 m (261ft) cross-sections with respect to key evaluation elements (wetland impacts, safety, and water quality impacts).

Table 3-7. Summary of Alternative ROW Widths

Evaluation Element	95 m (312 ft) ROW with Open Median	87 m (285 ft) ROW with Median Barrier	80 m (261 ft) ROW with Median Barrier and Reduced Buffer
Wetland impacts	99 acres	98 acres (96 acres, with 2 potential additional acres of impact to construct detention basins).	96 acres (with at least 2 potential additional acres of impact to construct retention basins).
Safety	Alternative E serves as baseline for comparing other ROW options.	Potential increase in vehicle accident rate over 95 m (312 ft) ROW.	Potential increase in vehicle accident rate over 95 m (312 ft) ROW. Potential increase in accident rate between vehicles and trail users.
Water quality impacts	Water quality treatment within proposed ROW (900 total ROW acres).	18.1 acres (detention) (898.1 total ROW acres) or more required for stormwater treatment, depending on treatment method.	18.1 acres (retention) (855 acres + 18.1 acres = 873.1 total ROW acres) or more required for stormwater treatment, depending on treatment method.

4.0 Glossary

AASHTO	American Association of State Highway and Transportation Officials
BMP	best management practice
CWA	Clean Water Act
FEIS	Final Environmental Impact Statement
FHWA	Federal Highway Administration
ft	feet
GIS	Geographic Information System
Green Book	*A Policy on Geometric Design of Highways and Streets* (AASHTO 2001)
HSIS	Highway Safety Information Systems
km	kilometers
m	meters
mi	miles
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
ROD	Record of Decision
ROW	right-of-way
SCDOT	South Carolina Department of Transportation
STA	State Transportation Agency
TSS	Total Suspended Solids
UDEQ	Utah Department of Environmental Quality
UDOT	Utah Department of Transportation
USACE	U.S. Army Corps of Engineers
VMT	vehicle-miles traveled

5.0 References

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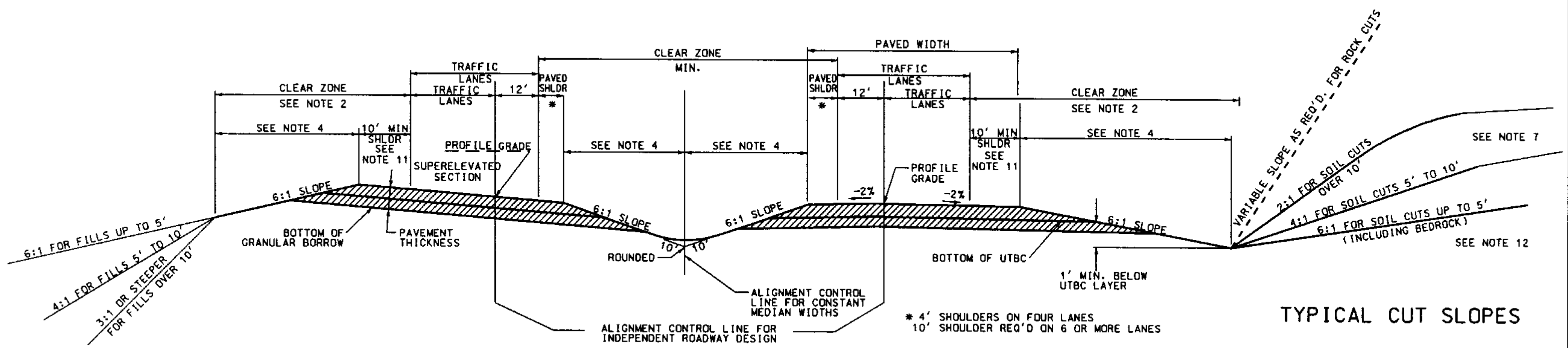
Appendix A

UDOT Standard Drawing DD4

MULTI-LANE

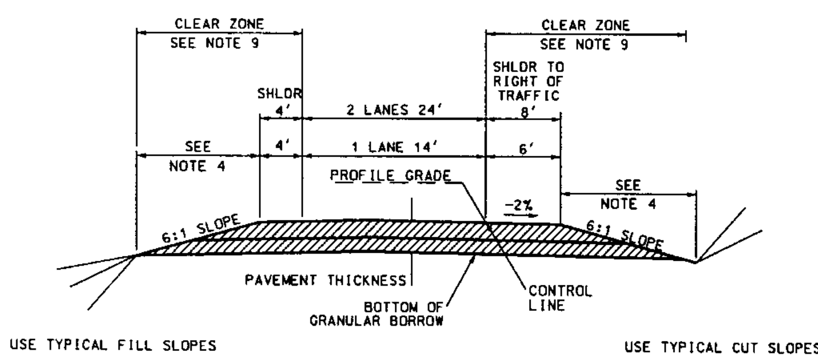


TYPICAL CUT SLOPES

TYPICAL SECTION ON CURVE

TYPICAL SECTION ON TANGENT

TYPICAL FILL SLOPES



TYPICAL RAMP

NOTES:

1. USE THE CURRENT EDITION OF AASHTO A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS FOR DESIGN OF ROADWAY ELEMENTS.
2. USE THE CURRENT EDITION OF AASHTO ROADSIDE DESIGN GUIDE FOR CLEAR ZONE REQUIREMENTS. CLEAR ZONE MAY EXTEND INTO CUT OR FILL SLOPES.
3. STANDARDS SHOWN ARE RECOMMENDED VALUES. EXCEED STANDARDS IF CONDITIONS PERMIT.
4. IN FILL CONDITIONS MAINTAIN A CONSTANT SLOPE FROM THE EDGE OF THE PAVEMENT TO THE OUTER EDGE OF THE CLEAR ZONE. IN CUT CONDITIONS MAINTAIN A CONSTANT SLOPE FROM THE EDGE OF THE PAVEMENT TO THE BOTTOM OF THE GRANULAR BORROW LAYER OR PROVIDE OTHER MEASURES TO DRAIN ALL PAVEMENT THICKNESS LAYERS. MAINTAIN A MINIMUM OF ONE FOOT VERTICAL DISTANCE FROM THE BOTTOM OF THE UTBC LAYER TO THE BOTTOM OF THE CUT DITCH. THERE MAY BE CUT FORESLOPES AND BACKSLOPES IN THE CLEAR ZONE.
5. TRANSITION FROM FLAT TO STEEPER CUT AND FILL SLOPES IN SUFFICIENT DISTANCE TO PROVIDE A NATURAL PLEASING APPEARANCE.
6. PAVEMENT THICKNESS CONSISTS OF HARD SURFACING, UTBC AND GRANULAR BORROW (IF USED).
7. INSTALL SURFACE DITCH (OPTIONAL) WHEN SHEET FLOW DRAINAGE IS TOWARDS CUT SLOPE. DRAIN SURFACE DITCH TO NATURAL DRAINAGE OR ROADSIDE DITCH. PROVIDE OTHER MEASURES TO PREVENT ERODING CUT SLOPES IF SURFACE DITCH IS OMITTED. SEE STD DWG DD 2 FOR DETAILS.
8. SEE STD DWG DD 2 FOR TYPICAL SECTION ON DITCH FLARING AND BENCHED SLOPE.
9. DESIGN SPEED CHANGES THROUGHOUT LENGTH OF RAMP. USE APPLICABLE CLEAR ZONE.
10. USE A 12' MINIMUM OUTSIDE SHOULDER WHEN HEAVY TRUCK TRAFFIC EXCEEDS 250 DDHV.
11. RANGE OF SUPERELEVATION IS THE PAVED WIDTH.
12. THE SLOPES SHOWN FOR CUT AND FILL HEIGHTS ARE SUGGESTED VALUES. SLOPES MAY DEVIATE FROM THESE SUGGESTED VALUES TO MEET PROJECT SPECIFIC REQUIREMENTS.

NO.	DATE	APPR.	REVISIONS / REMARKS
1	12/18/03	S.D.	MULTI-LANE DETAIL MODIFIED,NOTES UPDATED

UTAH DEPARTMENT OF TRANSPORTATION
STANDARD DRAWINGS FOR ROAD AND BRIDGE CONSTRUCTION
SALT LAKE CITY, UTAH

RECOMMENDED FOR APPROVAL: CHAIRMAN STANDARDS COMMITTEE — DEC. 18, 2003 DATE
APPROVED: DEPUTY DIRECTOR — DEC. 18, 2003 DATE

GEOMETRIC DESIGN FOR FREEWAYS (ROADWAY)
STANDARD DRAWING TITLE

STD DWG
DD 4

Appendix B

Association of Median Width and Highway Accident Rates

Association of Median Width and Highway Accident Rates

MATTHEW W. KNUIMAN, FORREST M. COUNCIL, AND DONALD W. REINFURT

Data for two states have been extracted from the Highway Safety Information System and used to examine the effect of median width on the frequency and severity of accidents. Log-linear models for accident rates have been used to describe the effect of median width after adjusting for other variables. Effects have been estimated by the quasi-likelihood technique assuming a negative-binomial variance for the accident count per roadway section. Results for both states indicate that total accident rates and rates for specific types and severity decline rapidly when median width exceeds about 25 ft (7.6 m). Policy guidelines for median widths are somewhat nebulous, partly due to the lack of large well-conducted studies providing quantitative information on this topic. The results provide a basis for the development of more precise guidelines regarding median width.

Medians on divided highways provide a recovery area for out-of-control vehicles. The median should be wide enough to allow an out-of-control vehicle sufficient space to recover without crossing over the median into opposing traffic. In addition, divided highways with wide medians provide a safety zone at access points for turning vehicles and entering vehicles wishing to cross one or both directions of traffic. A variety of median types are in use, with narrow medians sometimes including barriers designed to positively prevent out-of-control vehicles from crossing the median into opposing traffic.

It has been suggested that the median width should be at least 60 ft (18.3 m) on rural highways and can be as low as 10 ft (3.1 m) on urban highways if median barriers are provided (*1*), but little research has been conducted providing quantitative measures of the effects of median width on the frequency and severity of related accidents. Early studies (*2–5*) were not able to establish definitive relationships between accident rates and median width; however, a subsequent study by Garner and Deen (*6*) has shown that wider medians have lower accident rates. The Garner and Deen study used 420 mi (676 km) of rural, four-lane, fully controlled access road sections [speed limit 70 mph (113 kph)] in Kentucky with median widths ranging from 20 to 60 ft (6.1 to 18.3 m) and involved a total of 2,448 accidents (1965–1968).

This paper examines the effect of median width on the frequency and severity of accidents on homogeneous highway sections with a traversable (nonbarrier) median. Highway sections with curbed medians or medians including barriers were also examined. However, there were insufficient sections of these types for meaningful statistical analysis.

Data extracted from the Highway Safety Information System (HSIS) for the states of Utah and Illinois are used. The Utah data involve 982 sections of highway for a total of 973.8 mi (1567.8 km) of roadway with 37,544 reported accidents over the period 1987 through 1990. The Illinois data involve 2,481 sections of highway for a total of 2,081.3 mi (3351 km) of roadway and 55,706 accidents over the period 1987 through 1989. Road sections with median widths ranging from zero (no median) to 110 ft (33.6 m) are examined.

METHODS

Data Base

HSIS developed and maintained for the Federal Highway Administration by the Highway Safety Research Center (HSRC) at the University of North Carolina, includes an accident data base, a road inventory data base, and a traffic volume file for five states (Illinois, Utah, Michigan, Minnesota, and Maine). All accidents reported to the police are included in the data base, and for each accident a variety of details are recorded, including date and location of accident, road and environmental conditions, accident type, and the number and severity of injuries. The road inventory data base contains the characteristics of homogeneous highway sections. The definition of homogeneous varies to some degree from state to state, but in most cases a new section is initiated any time there is a change in a major geometric or cross-section variable (e.g., lane width, pavement type, shoulder width or type, number of lanes, etc.). For this study, homogeneous sections of highway were defined as contiguous segments for which the following variables did not change: federal aid system, functional classification, rural/urban designation, predominant terrain type, average annual daily traffic volume (both directions), one- or two-way operation, number of lanes, average through lane width, posted speed limit, access control, median width and type, left shoulder width, and right shoulder type.

The traffic volume file contains the average annual daily traffic volume. Using route number and mile points, these three files can be merged to obtain the number, rate, severity, and type of accidents that have occurred on specific highway sections over a given period of time.

Extensive checking and preliminary investigation indicated that the accident and roadway data for two of the five states

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(Utah and Illinois) were of adequate completeness and reliability for an analysis investigating the effect of median width on accident rates. The Utah and Illinois data were described by Council and Hamilton (*7*) and Council and Williams (*8*), respectively.

Several roadway characteristics in addition to median width affect the frequency, severity, and type of accidents. To isolate the effect of median width, these other variables must be controlled either by restricting the road sections to have particular characteristics or through statistical adjustment. In this study both methods of control were used.

The analyses have for the most part been restricted to two-way, four-lane, rural and urban Interstate, freeway, and major highway road sections of length exceeding 0.07 mi (0.11 km), with posted speed limit at least 35 mph (56 kph) and with median widths ranging from zero (no median) to 110 ft (33.6 m). A section length of 0.07 mi (0.11 km) was chosen as the minimum length for which reported accident locations could be considered reliable for merging with the road inventory data base. Sections on minor roads were eliminated because many had missing data and virtually all had no median. After these were eliminated, there were very few sections with speed limit less than 35 mph (56 kph), so the remaining few were also eliminated. There were also a few sections with median width ranging from 111 ft (33.9 m) to 999 ft (304.7 m), and these were eliminated because they were possibly in error and would have a large influence on the median width coefficients in a regression model. In addition, the Utah analysis was restricted to road sections with lane width of 12 ft (3.7 m). There was no explicit lane width variable for Illinois, and it could not be reliably calculated from other variables; thus no such restriction was applied for Illinois.

Median width is defined as the width of the portion of divided highway separating the traveled ways for traffic in opposite directions (and includes the inside shoulder). Other variables considered in the statistical analyses were as follows: functional classification (categorized as rural–Interstate/freeway, rural–other major road, urban–interstate/freeway, urban–other major road), posted speed limit [35 to 40, 45 to 50, 55, and 65 mph (56 to 64, 72 to 81, 89, and 105 kph)], right shoulder width, access control (full, partial, none), curvature (value 1 if curvature greater than 1 degree, 0 otherwise), average daily traffic (average number of vehicles per day), and section length [in miles (kilometers)]. Access control data were not reliable for Utah (on the basis of information from state data experts) and were therefore not considered in the Utah analysis. Furthermore, 23 percent of the Utah sections did not have speed limit recorded and thus an additional category "missing" was used for this variable. Curvature was not considered in the Illinois analysis because the data were incomplete.

The Utah analysis was based on 982 sections of highway for a total of 973.8 mi (1567.8 km) of roadway [average section length 0.99 mi (1.6 km)], and the Illinois analysis involved 2,481 sections of highway for a total of 2,081.3 mi (3350.9 km) of roadway [average section length 0.84 mi (1.35 km)].

For each Utah road section, the number of accidents over the 4-year period 1987–1990 was obtained (giving a total of 37,544 accidents), whereas for Illinois the 3-year period 1987–1989 was used (giving a total of 55,706 accidents). The 1990 Illinois data did not yet exist in the HSIS files at the time of this analysis. Each accident had a severity code representing the most serious injury in the accident (K = fatal, A = incapacitating injury, B = nonincapacitating injury, C = possible injury, PDO = property damage only). The number of total accidents and the number of each severity type were determined for each section of road for use in total, A + K, C + B + A + K (i.e., all injury), and PDO crash rates.

The accident data from both states also provided numerous variables concerning the nature of the accident, including accident type, collision sequence (in Utah), and vehicle movements preceding and during the accident sequence. An attempt was made to define a smaller number of accident categories based on "potential median involvement"—the degree to which the presence and width of a median might potentially affect the crash rate. This categorization was based on the assumption that the basic goals of a median are (*a*) to separate opposing vehicles, (*b*) to provide a vehicle with a safe clearzone that can be used to avoid vehicles traveling in the same direction, (*c*) to provide a refuge for turning or crossing vehicles, and (*d*) to provide a safe clearzone to reduce the number of ran-off-road object impacts. In the resulting categorization, each accident was coded as a multivehicle collision or single-vehicle accident. In addition, head-on/sideswipe opposite direction collisions and single-vehicle rollover crashes were identified. If an accident involved a sequence of two or more events (as could be ascertained in the Utah data), collision with another vehicle took precedence over a single vehicle event, head-on/sideswipe opposite direction collision took precedence over other types of collisions, and rollover took precedence over other single-vehicle events. Counts of each of these types of crashes were made for each roadway section for use in calculating the rates.

Statistical Methods

The accident rate per 100 million vehicle miles traveled for an individual road section was calculated as

$$R = (Y/VM) * 10^8$$

where

R = observed rate,
Y = observed number of accidents,
VM = vehicle miles of travel calculated as $ADT * 365 * T * L$,
ADT = average daily traffic (vehicles per day),
T = number of years over which accidents were counted, and
L = section length (mi) (1 mi = 1.61 km).

Accident rates corresponding to all accidents, serious injury accidents (A or K), injury accidents (C, B, A, or K), PDO accidents, multivehicle accidents, head-on or sideswipe opposite direction accidents, single-vehicle accidents, and single-vehicle rollover accidents have been analyzed using regression models. The specific aims of the modeling process were to obtain standard errors and confidence intervals for estimated accident rates and to determine whether the observed reduction in the crude accident rates for wider medians persisted after adjusting for other roadway variables.

A log-linear regression model was used to simultaneously assess the effects of median width and several other roadway variables on the accident rate. This model may be represented algebraically as

$$\log(\lambda) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k$$

where

λ = expected value of $R = E(R) = [E(Y)/VM] * 10^8$ (log denotes logarithm to base e), and

X_i = indicator (dummy) variables for categorical roadway characteristics (e.g., functional class) or actual values for quantitative roadway characteristics (e.g., right shoulder width).

Note that $\exp(\beta_i)$ (i.e., e^{β_i}) represents the relative effect of a unit change in X_i on the accident rate.

Log-linear models assume that the effect of variables on the accident rate is multiplicative rather than additive as in linear models. Estimated rates from log-linear models cannot be negative. Log-linear models have been widely used in statistical analyses of count data [see McCullagh and Nelder (*9*) and references therein] and have recently been used in transportation studies by Joshua and Garber (*10*) for truck accident rates, Hauer and Persaud (*11*) for railway-crossing accident rates, and Zegeer et al. (*12*) for highway accident rates. Zegeer et al. (*12*) considered both additive and multiplicative (i.e., log-linear) models and concluded that the multiplicative models provided a better fit to the data.

To obtain estimates, standard errors, and confidence intervals, the negative-binomial variance function was assumed for the accident count per section, that is,

$$Var(Y) = E(Y) + K * [E(Y)]^2$$

where K has the same value for all sections and $Var(Y)$ and $E(Y)$ are the variance and expected value, respectively. The classical distribution for accident counts is the Poisson distribution for which the variance is equal to the mean. However, variances in excess of the mean are often observed (*13*), partly because not all relevant variables are included in the model. The negative binomial distribution is a natural extension of the Poisson, which accounts for this excess variability and has certain desirable theoretical properties (*14*). The negative-binomial distribution for accident counts has been used recently by Hauer and Persaud (*11*) and Hauer et al. (*15*), and these authors have validated its use for transportation studies. Maher (*16*) also used the negative binomial distribution to explain traffic accident migration and states that "it has become standard" to use this distribution. This assumption was validated in our study by calculating the mean and variance of Y (for total accidents) for homogeneous subgroups of road sections and plotting the variance against the mean.

The beta coefficients in the regression model were estimated by the method of quasi-likelihood, and the value of K was estimated by the method of moments (*9*). Others have used maximum likelihood estimation (*11,15*), but it has been suggested that quasi-likelihood estimation for the beta coefficients and the method of moments for K is a more robust estimation procedure (*14*) and therefore have been used here. The estimation procedures were carried out using the statistical package GLIM (*17*), and the GLIM macros (or procedures) for fitting these models are given by Breslow (*13*). For Utah, the estimated value of K was about 0.6 and for Illinois it was about 1.4, suggesting that accident rates for similar sections of highway are more variable in Illinois. This is most likely due to greater variability in driver and environmental conditions in Illinois than in Utah.

In the regression models, median width has been examined both as a categorical variable (six categories for Utah and eight categories for Illinois) and as a continuous variable in the form of a quartic (fourth-degree) polynomial function without a linear term, because this particular function closely resembled the observed rates. When median width has a categorical representation, no trend is assumed, whereas the continuous representation adopted in this study assumes a quartic polynomial trend on the log scale for the accident rates. As in all continuous forms of modeling, the data are "smoothed" by the assumed trend. By using both representations, comparison of the estimated rates (and confidence intervals) for the categories allows a check on the appropriateness of the form of the assumed trend in the continuous model. In all cases the trends were consistent with a quartic polynomial trend. For comparison purposes, in this paper results for both forms of representation are reported.

The purpose of the analysis was to determine the effect of median width on the accident rate after controlling or adjusting for other variables. Variables that have been controlled by design through restricting the analysis to particular (homogeneous) sections were listed earlier. Variables included in the regression models are functional classification (rural–Interstate/freeway, rural other, urban–Interstate/freeway, urban other), posted speed limit, right shoulder width (continuous), access control (none, partial, full—Illinois only), curvature (dichotomous as described above—Utah only), log (average daily traffic) (continuous), and log (section length) (continuous). Section length was included as a surrogate for other variables not included that may be correlated with section length. Because the sections were constructed to be homogeneous, shorter sections occur where the roadway characteristics are changing more rapidly.

Many of the variables included in the regression model were correlated with median width, and several combinations of median width and other variables had very few or no sections. For example, Interstate road sections had larger median widths, whereas other functional classes had smaller median widths, although there was some overlap. This made the fitting of interactions between median width and other variables difficult. Where possible, such interactions were examined, but no significant interactions were found.

The estimated effects of median width obtained from these models (especially those with a categorical representation) may be conservative, since when variables correlated with median width are included in the models, they will absorb some of the effect of median width. For example, if functional class is omitted from the model, the effect of median width increases and vice versa. Inclusion of such variables has been done deliberately so that any median width effects detected cannot be attributed to other confounding variables.

RESULTS

Table 1 gives the characteristics of the road sections that have been used in the accident rate analyses. Because there were fewer sections in the Utah data, only six median width categories were used rather than eight as for Illinois. Note also that there were very few sections in the Utah data with median width in the range 30 to 54 ft (9.2 to 16.5 m) and very few sections with functional classification as urban–Interstate/freeway.

The crude average accident rates by median width for total accidents and severity and collision types are given in Table 2. The total accident rate appears to decline steadily with increasing median width. For Utah it declines from 650 for sections with no median to 111 accidents per 100 million vehicle-mi (179 accidents per 100 million vehicle-km) traveled for sections with median width at least 85 ft (25.9 m). Thus the crude total accident rate is reduced by a factor of about 6 over this range of median width. The decrease in the total accident rate for Illinois declines by a factor of about 13.

Serious injury (i.e., AK), all injury (CBAK), and property-damage-only accidents also show many-fold reductions over this range of median width. The rate for multivehicle accidents declines steadily with increasing median width, and head-on/sideswipe opposite direction accidents in particular show a dramatic decrease with increasing median width. On the contrary, the rates for single-vehicle accidents (Utah) and single-vehicle rollover accidents in particular show little relationship to median width.

The many-fold reductions observed in these accident rates cannot all be attributed to the effect of median width because of confounding by other variables. It is for this reason that the models including these confounding factors are developed. The relative effect of median width on the total accident

TABLE 1 Number of Sections (N), Number of Roadway Miles (Miles) with Various Characteristics for Utah and Illinois

Utah Category	Utah N	Utah Miles	Illinois Category	Illinois N	Illinois Miles
Overall	982	973.8		2481	2081.3
Median Width (ft)					
0	176	68.7	0	567	219.0
1-10	257	110.9	1-24	199	67.0
11-29	213	114.7	25-34	176	89.4
30-54	52	76.8	35-44	479	304.2
55-84	179	298.7	45-54	200	139.7
85-110	105	303.9	55-64	450	538.4
			65-84	239	424.6
			85-110	171	298.9
Functional Class					
rur_int	284	653.0	rur_int	846	[illegible]
rur_oth	130	73.5	rur-oth	343	[illegible]
urb_int	64	43.9	urb_int	436	[illegible]
urb_oth	504	203.3	urb_oth	856	[illegible]
Speed Limit					
35-40	183	61.6	35-40	370	128.8
45-50	118	44.7	45-50	348	174.1
55	146	101.8	55	889	[illegible]
65	305	663.9	65	874	[illegible]
missing	230	101.7			
Right Shoulder Width (ft)					
0	315	119.2	0	401	155.0
1-5	121	62.3	1-5	65	25.6
6-10	495	768.5	6-10	1406	1223.0
11-23	51	23.9	11-23	609	677.6
Curvature > 1 Degree					
no	756	605.6		NA	
yes	226	368.2			
Access Control					
none		NA	NA	872	356.8
partial				435	216.9
full				1174	1507.6

NOTE: 1 mi. = 1.61 km, 1 ft. = 0.305 m

TABLE 2 Crude Average Accident Rates per 100 Million Vehicle-mi and Estimated Relative Effects of Median Width on the Total Accident Rate [Median Width Is Represented Both as a Categorical Variable and as a Continuous Variable, Adjusting for Functional Class, Posted Speed Limit, Right Shoulder Width, Access Control (Illinois Only), Curvature (Utah Only), Log (ADT) and Log (Section Length)]

Median Width (MW)			Average Accident Rate (R)								Relative Effect on Total Accident Rate		
											Categorical		Continuous
Category	Mean	N	AK	CBAK	PDO	MVeh	SVeh	HO	Roll	Total	Estimate	95% Conf Int	Estimate
Utah													
0	0.0	176	48	220	430	522	127	10	14	650	1.00	(1.00, 1.00)	1.00
1-10	9.4	257	47	203	416	521	97	10	5	618	1.06	(0.89, 1.26)	0.96
11-29	14.9	213	45	159	303	373	89	8	7	462	0.97	(0.81, 1.17)	0.91
30-54	46.3	52	19	53	106	51	109	1	29	159	0.56	(0.36, 0.88)	0.61
55-84	71.7	179	20	42	95	31	106	1	22	137	0.51	(0.34, 0.78)	0.52
85-110	101.0	105	22	44	67	18	93	0	29	111	0.47	(0.30, 0.71)	0.47
ALL	32.0	982	38	142	282	321	103	6	14	424			
Illinois													
0	0.0	567	46	214	477	605	86	21	5	692	1.00	(1.00, 1.00)	1.00
1-24	12.8	199	40	194	452	578	69	12	8	647	1.05	(0.86, 1.28)	0.96
25-34	29.8	176	42	115	177	200	92	3	15	292	0.81	(0.62, 1.06)	0.84
35-44	39.7	479	16	48	82	78	51	2	6	129	0.77	(0.59, 0.99)	0.76
45-54	49.2	200	10	37	90	66	61	2	7	127	1.00	(0.74, 1.35)	0.69
55-64	63.8	450	5	14	31	18	27	1	3	45	0.62	(0.46, 0.83)	0.62
65-84	71.9	239	7	18	41	19	40	1	5	59	0.64	(0.46, 0.88)	0.60
85-110	88.9	171	6	20	34	18	36	1	6	53	0.68	(0.48, 0.96)	0.65
ALL	39.4	2481	22	91	193	226	58	7	6	283			

NOTE: 1 ft. = 0.305 m

Mean = average median width
N = number of road sections
Total = overall accident rate
AK = A+K rate
CBAK = all injury rate
PDO = property damage only
MVeh = multi-vehicle accident rate
SVeh = single-vehicle accident rate
HO = head-on/sideswipe opposite direct. rate
Roll = single-vehicle rollover rate

rate after adjustment for other variables via the log-linear regression model is also given in Table 2 and shown graphically in Figure 1. The estimate and standard error of the coefficients for fitted log-linear models showing the continuous effect of median width and the other independent variables are presented in Table 3.

The continuous estimates given in Table 2 were obtained by inserting the average median width for each category into these equations. The interpretation of these relative effects is that, when all the other variables are the same and the only difference is the median width, the relative effect describes the proportional reduction in the total accident rate. For example, using the Illinois equation (continuous), the total accident rate for an average median width of 40 ft (12.2 m) is about 76 percent of the rate for median width zero (no median), and for an average median width of 64 ft (19.5 m) (see Table 3 for mean of interval) it is 62 percent. An estimate of the safety benefit of increasing the median from 40 to 64 ft (12.2 to 19.5 m) is obtained as (0.62 − 0.76)/0.76 = −0.18. Therefore, one would expect an 18 percent reduction in the

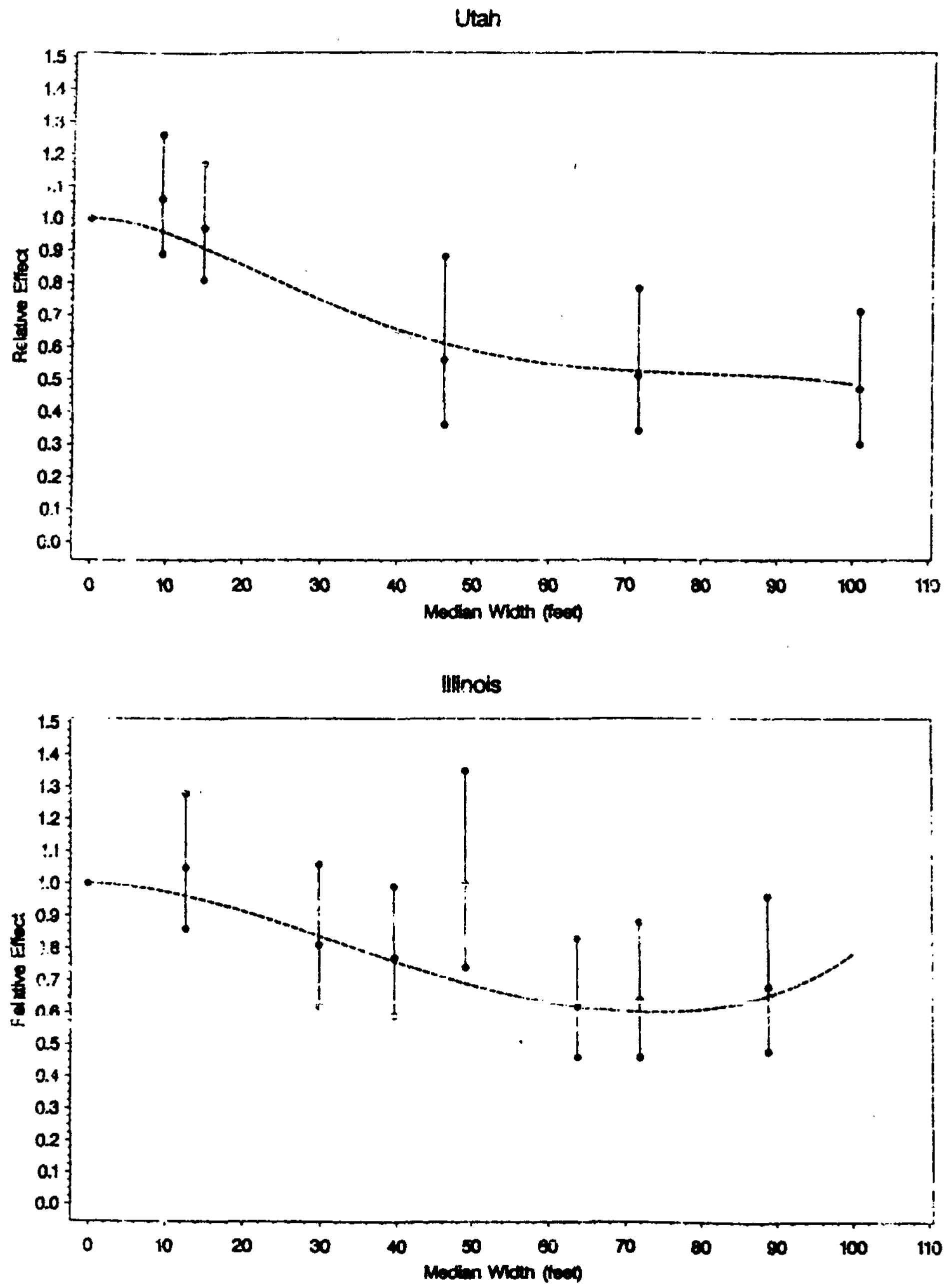

FIGURE 1 Estimated relative effects of median width on the total accident rate when median width is represented both as a categorical variable and as a continuous variable, adjusting for functional class, posted speed limit, right shoulder width, access control (Illinois only), curvature (Utah only), log (ADT) and log (section length). Note: 1 ft = 0.305 m.

TABLE 3 Fitted Log-Linear Regression Models for Total Accident Rate Showing Continuous Effect of Median Width and Other Variables

	Parameter	Estimate	Standard Error
UTAH			
	Constant	6.196	0.2943
	Median width^2	-5.589×10^{-4}	3.549×10^{-4}
	Median width^3	8.940×10^{-6}	7.083×10^{-6}
	Median width^4	-4.105×10^{-8}	3.716×10^{-8}
	Rural other vs rural interstate	-1.078	0.2757
	Urban interstate vs rural interstate	-0.2911	0.1714
	Urban other vs rural interstate	-0.5081	0.2782
	Curvature > 1 degree	0.0456	0.0754
	Right shoulder width	-0.0352	0.0082
	Speed limit 45-50 vs 35-40	0.5187	0.1097
	Speed limit 55 vs 35-40	0.4679	0.1149
	Speed limit 65 vs 35-40	-0.5417	0.2015
	Speed limit missing vs 35-40	0.6461	0.1041
	Log (average daily traffic)	-0.1389	0.0448
	Log (section length)	-0.1962	0.0308
Illinois			
	Parameter	Estimate	Standard Error
	Constant	4.587	0.1655
	Median width^2	-2.622×10^{-4}	2.397×10^{-4}
	Median width^3	2.062×10^{-6}	5.799×10^{-6}
	Median width^4	3.167×10^{-9}	3.740×10^{-8}
	Rural other vs rural interstate	0.4293	0.1308
	Urban interstate vs rural interstate	-0.0566	0.0975
	Urban other vs rural interstate	0.7921	0.1368
	Access control partial vs none	0.3723	0.1298
	Access control full vs none	0.4546	0.1280
	Right shoulder width	-0.0460	0.0110
	Speed limit 45-50 vs 35-40	0.5541	0.1140
	Speed limit 55 vs 35-40	0.5121	0.0962
	Speed limit 65 vs 35-40	-0.5434	0.1000
	Log (average daily traffic)	-0.2509	0.0495
	Log (section length)	-0.1232	0.0251

accident rate. On the other hand, if one reduced an existing median of 64 ft (19.5 m) to a median of 40 ft (12.2 m), one would expect a 23 percent increase in the total accident rate [(0.76 − 0.62)/0.62 = 0.23].

Thus the decline in the crude total accident rates with increasing median width given in Table 2 persists, albeit it to a lesser degree, after adjustment for these other confounding variables. Similar trends are shown for Utah and Illinois. These results indicate that there is little reduction in the accident rate for median widths up to about 25 ft (7.6 m). Whereas this lack of decrease is not as apparent in the smoothed continuous models, the categorical estimates for the smaller median widths are a little greater than 1.0 (indicating no difference from a median width of zero). The decline in accident rate, particularly in the categorical model, is most apparent for median widths beyond about 20 to 30 ft (6.1 to 9.2 m). The decreasing trend seems to become level at median widths of approximately 60 to 80 ft (18.3 to 24.4 m), particularly for Illinois.

The estimated relative effects for serious injury, all injury, and property-damage-only accident rates are given in Table 4. Logic suggests that the effect should be stronger for more severe accidents because wider medians would reduce the likelihood of collisions between vehicles traveling in opposite directions, which tend to have serious injury consequences. However, although the effect of median width on the accident rate is slightly stronger for injury accidents (but not AK accidents) than for property-damage-only accidents for Utah, the effect appears to be much the same for all severity classes for Illinois.

The estimated relative effects (continuous model) for multivehicle, single-vehicle, head-on/sideswipe opposite direction, and single-vehicle rollover accident rates are shown in Figure 2. For Utah the effect of median width is very similar for multivehicle and single-vehicle accidents, whereas for Illinois the effect is larger for multivehicle accidents, as might be expected intuitively.

More specifically, one might expect that median width would have its most dramatic effect on head-on/sideswipe opposite direction accidents. This is demonstrated clearly by the Illinois data. However, for Utah, although median width appears to have a dramatic effect on head-on/sideswipe opposite direction accidents after about 40 ft (12.2 m), the size of the effect is somewhat similar to the effect for multivehicle accidents in general.

Median width had little effect on single-vehicle rollover accidents for Illinois but appeared to have a rather sizable effect for Utah.

TABLE 4 Estimated Relative Effects of Median Width on Serious Accident Rates (AK), Injury Accident Rates (CBAK), and Property-Damage-Only Accident Rates (PDO) [Uses Models in Which Median Is Represented Both as a Categorical (cat) and as a Continuous (cts) Variable, Adjusting for Functional Class, Posted Speed Limit, Right Shoulder Width, Access Control (Illinois Only), Curvature (Utah Only), Log (ADT), and Log (Section Length)]

	Median Width	(Mean)	AK cat	AK cts	CBAK cat	CBAK cts	PDO cat	PDO cts
UTAH								
	0	(0.0)	1.00	1.00	1.00	1.00	1.00	1.00
	1-10	(9.4)	0.95	0.96	0.92	0.94	1.10	0.97
	11-29	(14.9)	1.01	0.91	0.91	0.86	0.99	0.92
	30-54	(46.3)	0.65	0.63	0.53	0.50	0.56	0.65
	55-84	(71.7)	0.62	0.57	0.48	0.46	0.51	0.52
	85-110	(101.0)	0.73	0.66	0.57	0.52	0.41	0.42
ILLINOIS								
	0	(0.0)	1.00	1.00	1.00	1.00	1.00	1.00
	1-24	(12.8)	1.00	0.97	1.04	0.98	1.07	0.95
	25-34	(29.8)	1.10	0.86	0.95	0.89	0.76	0.81
	35-44	(39.7)	0.88	0.77	0.84	0.80	0.72	0.74
	45-54	(49.2)	0.84	0.68	0.97	0.72	1.04	0.69
	55-64	(63.8)	0.60	0.57	0.60	0.61	0.63	0.64
	65-84	(71.9)	0.68	0.54	0.67	0.58	0.63	0.64
	85-110	(88.9)	0.58	0.57	0.64	0.64	0.70	0.67

NOTE: 1 ft. = 0.305 m

The results for head-on/sideswipe opposite direction and for rollover accidents should be interpreted with some caution, especially for Utah, because there were very few accidents of these types. For Illinois, 1,980 sections (out of a total of 2,481) and, for Utah, 699 sections (out of a total of 982) had no head-on/sideswipe opposite direction accidents, whereas 2,241 sections in Illinois and 907 sections in Utah had no single-vehicle rollover accidents.

CONCLUSIONS

This investigation represents an attempt to define the relationship between median width and accident rate while controlling for other confounding variables. Although there were some studies in the prior literature relating to median width, in general the literature on this subject is quite sparse. Thus, there is little available information on an issue that is even more critical today given the current movement toward adding lanes to multilane facilities to enhance capacity without purchasing additional right-of-way. Thus, even with the caveats stated below, this study is a beginning point in the development of much needed information related to median width and safety.

This study has the advantage of a more comprehensive data base than prior studies. In addition, the data used here are more current than the data in the older studies, and we were able to use data from two states rather than only one, which allowed us to look at consistency of findings between the states. Furthermore, there is greater mileage of four-lane divided highway and thus miles of median in each of the study states than had been the case in earlier studies, along with a wider range of median widths.

There are, however, some necessary caveats that must be stated. First, in any study that attempts to control for confounding variables through statistical means rather than through the design of the study (i.e., by actually assigning different median widths to similar sections of the highways), the validity of the results depends on how well the confounding variables are identified and measured. Whereas we attempted to control for major confounding variables in the analyses conducted here, there are clearly other variables that were either not measured in our data base or not used in the final model simply because of the need to limit the model to as few variables as possible. These possible confounding variables include vertical grade, median slope, type of traffic (e.g., percent heavy trucks), environmental factors, additional geometric variables related to details of curvature or sideslope design, and general exposure factors. Even with these caveats, the results are important.

The general findings indicate that accident rates decrease with increasing median width, even when other confounding variables are controlled for. Whereas the degree of improvement due to median width was not exactly the same in the Utah data as in the Illinois data, the same general trends were observed in the two states. Second, it was also apparent that there was very little decrease, if any, in the various accident rates for medians less than approximately 20 to 30 ft (6.1 to 9.2 m) in width in the two states. Thus, in terms of modification of existing roadways, this finding indicates that decreasing any median width that is greater than 20 to 30 ft (6.1 to 9.2 m) to 30 ft (9.2 m) or less to enhance capacity would probably be accompanied by a decrease in the level of safety on the roadway. [Unfortunately, we could not determine the exact "breakpoint" where the safety effect ends. Whereas the categorical data from both states indicated no safety effect

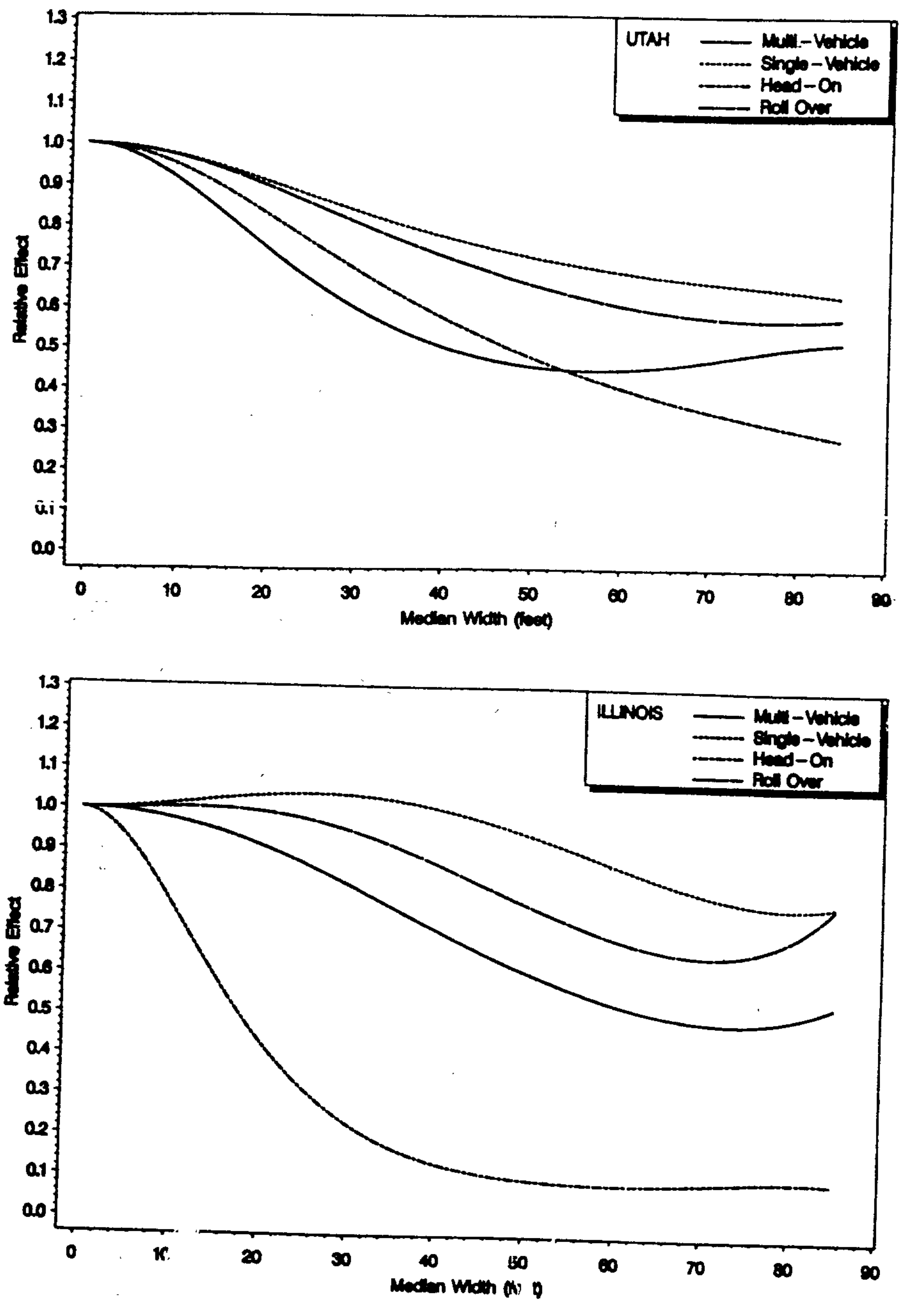

FIGURE 2 Estimated relative effects of median width on multivehicle accident rates, single-vehicle accident rates, head-on/sideswipe opposite direction accident rates, and single-vehicle rollover accident rates from models in which median width is represented as a continuous variable, adjusting for functional class, posted speed limit, right shoulder width, access control (Illinois only), curvature (Utah only), log (ADT), and log (section length). Note: 1 ft = 0.305 m.

for medians less than approximately 20 to 25 ft (6.1 to 7.6 m), there were not adequate numbers of 20-ft (6.1-m), 25-ft (7.6-m), or 30-ft (9.2-m) medians to allow separate analyses of these individual categories.]

There were also differences noted from what might have been traditionally hypothesized as the manner in which median width affects safety. For example, it might have been hypothesized that median width would be primarily related to decreases in "crossover accidents" involving head-on crashes between opposing vehicles. As a result of reducing these crossover accidents, changes in median width might have been expected to have a much greater effect on severe crashes than on less severe or property-damage-only crashes. We did not find either to be the case. As noted above, whereas we found significant changes in head-on crashes in both states, the changes in head-on crashes were only a small part of the overall decrease in total multivehicle accidents in each state. In addition, we did not find much difference in the effects of width on accident severity—the less severe crashes were affected as much as the more severe.

However, these results are not as surprising as first thought if viewed under the earlier-stated modified assumption of how medians affect safety. If instead of just acting as a buffer between vehicles that run off the road left toward each other, it is assumed that a median may well be serving as an escape area or clearzone for vehicles that are avoiding possible crashes with vehicles in their own lanes, one would see decreases in multivehicle crashes of all types (even rear-ends) and perhaps increases (or no change) in single-vehicle accidents due to the additional "roadside" to run off into. This is indeed what we found in the data—clear decreases in multivehicle crashes of all types and lesser or no decreases in the single-vehicle ran-off-road type crash.

Thus, in summary, it may be that we need to view the median differently, and this new view may affect median design. If the median is to "sell itself" to the driver as a safe escape area, it must clearly be wide enough to give the motorist the perception of safety. If the median is so narrow that heavy oncoming traffic on the opposing roadway reduces the perception of additional safety, it will not be used as much, and accident reductions will decrease.

A major point of interest is how these findings agree with design guidelines provided in the AASHTO *Policy on Geometric Design* (*1*). It is difficult to summarize AASHTO median-width and barrier-need guidelines, since material is found in a variety of sections of the *Policy* and because "hard" guidelines are not presented. This is due, of course, to the lack of hard data on the issue.

The general guideline provided is that careful study is needed of all locations. With respect to rural arterials, it appears that the policy suggests that medians of 60 ft (18.3 m) or more should be provided whenever feasible. In locations with restricted right-of-way, medians of 30 ft (9.2 m) or more are recommended. However, the additional information related to median width at intersections on rural arterials confuses the issue somewhat. Here, it is suggested that median widths of 12 to 30 ft (3.7 to 9.2 m) function quite well in that they provide room for turn lanes and, thus, protect turning vehicles; that median widths of 30 to 50 ft (9.2 to 15.3 m) may be suitable if detailed study of operational characteristics of the traffic are conducted; but that medians of 50 to 80 ft (15.3 to 24.4 m) ". . . have developed accident problems in some cases. . ." Thus, the designer is left with the impression that wider medians should not be used in places where at-grade intersections are present.

With respect to urban freeways, the general guideline is again to use medians that are as wide as possible. On four-lane facilities in areas of restricted right-of-way, it is suggested that 10-ft (3.1-m) medians are acceptable as long as a positive barrier is used. For six-lane facilities, a minimum width of 22 to 26 ft (6.7 to 7.9 m) is acceptable, again as long as a barrier is used. It is also interesting to note that a 50-ft (15.3-m) median is shown as a typical (nonbarrier) median width in a figure depicting a typical cross section with a median.

With respect to rural freeways, even less guidance is given. It is noted that 50- to 90-ft (15.3- to 27.5-m) medians are common. In sketches of typical cross section, a 50-ft (15.3-m) median is shown. It is further noted that in suburban areas, restricted right-of-way may lead to medians in the range of 10 to 30 ft (3.1 to 9.2 m) and that in these cases "median barrier is usually warranted as a safety measure."

Given the "softness" of the guidelines presented in the AASHTO policy, it is difficult to say whether the findings of this study support the design policy presented there. In this study, we find evidence that medians that are 50 ft (15.3 m) wide are indeed much safer than the no-median or narrow median condition. However, we also find that even wider medians [up to 80 ft (24.4 m) or more] appear to provide even greater safety benefits. If one takes literally the advice provided by the AASHTO guidebook concerning the need for barriers on either 10-ft (3.1-m) or 20- to 26-ft (6.1- to 7.9-m) medians, one might assume that four-lane medians greater than 15 ft (4.6 m) in width might be acceptable without barriers. Our findings do not support this at all. Indeed, the data here indicate that one needs to have a median at least 20 to 30 ft (6.1 to 9.2 m) in width before any safety effect is seen and that there are significant increases in the level of safety as one moves from 30 ft (9.2 m) to the wider median widths. Thus, in the design of new highways, our findings would support medians considerably wider than 30 to 40 ft (9.2 to 12.2 m).

This same information can be used in a slightly different way to provide information to the designer who is looking at the situation of potential lanes being added within the median. The conclusion from these data would be that safety benefits will indeed be lost by narrowing a median to any extent, and that if the median is narrowed to a width of between 20 ft (6.1 m) and 30 ft (9.2 m) (or less), essentially all of the safety benefit of the median may be lost unless a positive barrier is used. Unfortunately, because of the lack of barrier sections in the data set, we could not analyze the question of the benefit of placing positive barriers in the median.

In terms of needed additional research, it appears that these data have provided new information with respect to width of nonbarrier medians and the effects on safety—medians wider than approximately 25 to 30 ft (7.6 to 9.2 m) have a significant safety benefit, and the wider the median the better, up to approximately 65 to 80 ft (19.8 to 24.4 m). However, the most obvious remaining gap in knowledge is when to install positive barriers. At what width do the benefits of reductions in severe (cross-median) crashes outweigh the increase in less severe crashes? To conduct such a study will require a large sample of medians of various widths [at least in the range of 0 to 50 ft (0 to 15.3 m)] with and without barriers—clearly a multistate study.

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DISCUSSION

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The authors examined the effect of median width on vehicle accident rate for multilane divided highway sections with a traversable or nonbarrier median. Log-linear regression models with a negative-binomial variance function were used to study the effect. The authors should be commended for addressing a very important, yet difficult, problem. Overall, this is a well-written paper that presents some interesting empirical results. However, some of the results seem to be questionable.

1. This study failed to separate paved inside shoulders from the rest of the median. Paved inside shoulders are part of the roadway immediately contiguous with the traveled way and are important features of divided multilane highways. Failing to consider "paved inside shoulder width" in this study posted two potential problems: (*a*) the model results on the effect of median width are difficult to interpret in a design context and (*b*) it is entirely possible that the paved inside shoulder width was associated with the accident rate, not the rest of median width. To illustrate, let the paved inside shoulder width be X_1 and the rest of median width be X_2. In addition, let the total median width be X ($= X_1 + X_2$) and the number of accidents be Y. Furthermore, assume that X_1 is correlated with Y and X_2 is independent of Y. We can show that the correlation coefficient of Y and X, denoted by ρ_{xy}, does not vanish and can be computed as $\rho_{xy} = \mathrm{Cov}(X_1, Y)/[\mathrm{Var}(Y)\mathrm{Var}(X)]^{1/2}$.

2. (Table 1) Does "right shoulder width" include both the width of paved and unpaved shoulders? It does not seem reasonable to have road sections with a right shoulder width of 23 ft. Two related questions are as follows: How many road sections have a right shoulder width of 13 ft or more? Were these road sections particularly influential in estimating model coefficients?

3. (Table 2) Many rural Interstate road sections in the Utah roadlog file were coded as having a median width of 99 ft, which really meant that the road section's median width was equal to or greater than 99 ft. How did the authors handle these road sections?

4. (Table 4) The estimated coefficients for ADT having an algebraic sign contrary to expectation. The estimated coefficient for log(ADT) was −0.1389 in the Utah model and −0.2509 in the Illinois model. Thus, both models indicated that, for road sections of a particular functional class (and speed limit and access control), as ADT increased, total accident rate decreased. This result is apparently not acceptable. One possible reason for this to occur is that ADT alone did not give a good description of the traffic condition. Variables related to highway capacity, such as the number of lanes, should be considered in the model. Another possible reason is the collinearity problem to be discussed later.

5. (Table 4) The estimated regression coefficients for "median width" have very low *t*-statistics, indicating that the effect of median width on accident rate was poorly determined from the data. For the Utah model, the *t*-statistics of the estimated coefficients for (median)^3 and (median)^4 were about 1.26 and −1.10, respectively. For the Illinois model, *t*-statistics of the estimated coefficients for (median)^2, (median)^3, and (median)^4 were about −1.09, 0.36, and 0.08, respectively. These low *t*-statistics were indications to the authors that they might have "oversmoothed" or "overinterpreted" the data. Therefore, the statements in this paper on the effect of median width, such as that the decreasing trend seems to become level at median widths of approximately 60 to 80 ft, particularly for Illinois, are questionable. Why not just consider the first- and the second-order terms [i.e., (median) and (median)^2]?

6. (Table 4) Some of the variables considered in the model were extremely collinear (e.g., functional class, speed limit, and access control were highly correlated with one another). This collinearity problem may have made the interpretation of the fitted log-linear regression models difficult and the results questionable.

Some examples of Item 6 are as follows:

- Unreasonable speed limit effect?—If we use the fitted models to shed some light on the effect of speed limit change (from 55 to 65 mph) in 1987 on accident rates for rural Interstate highway sections, we would find that the models suggested a 64 and a 65 percent reduction in total accident rate for Utah and Illinois, respectively. These results cannot be supported by any highway statistics. This is probably a result of the distortion produced by the collinearity of some of the covariates. The computation of these reductions can be carried out as follows: Take Utah for example. Let the accident rates of any rural Interstate road section before and after the speed limit change be λ_{55} and λ_{65}, respectively. Provided that everything else was the same, the fitted model suggested that the ratio of these two accident rates would be $\lambda_{65}/\lambda_{55} = \exp(-0.5417)/\exp(0.4679) = \exp(-1.0096) = 36$ percent. Therefore, according to the model, the drop in accident rate on a rural Interstate section as a result of the speed limit change would have been 64 percent.

• Unexpected signs in coefficients for functional class variables?—For Utah, the estimated coefficients for functional class variables (i.e., "rural other versus rural Interstate," "urban Interstate versus rural Interstate," and "urban other versus rural Interstate") were negative (i.e., −1.078, −0.2911, and −0.5081, respectively). The negative sign also appeared in the Illinois model for "urban other versus rural Interstate." If we disregard other variables and focus on functional class variables alone, the Utah model suggests that rural other highways, urban Interstates, and urban other highways had a lower total accident rate than that of rural Interstates, which was contrary to what one would usually expect. But because functional class, speed limit, and ADT are highly correlated with one another, it may not be appropriate to examine functional class variables alone. The authors should make this clear in the paper.

Now, consider two hypothetical road sections in Utah: one rural and one urban Interstate section. Assume that these two road sections have the same geometric design characteristics, section length, and speed limit. Furthermore, assume that the rural and urban road sections have an ADT of 5,000 and 50,000 vehicles, respectively. Then, according to the model, the ratio of the accident rate between these two road sections is $\lambda_{urban}/\lambda_{rural} = \exp\{-0.2911 - 0.1389 \times [\log_e(50{,}000) - \log_e(5{,}000)]\} = \exp(-0.611) = 54$ percent. That is, the total accident rate of the urban road section is 46 percent lower than that of the rural road section. It is arguable that this ratio does not seem to be reasonable. More information will be needed for the readers to make a better judgment on this. For example, the authors may want to (*a*) cross-classify the number of road sections by functional class, speed limit, access control, and ADT in Table 1 and (*b*) tabulate the accident rate by functional class, speed limit, access control, and ADT.

• Unexpected signs in coefficients for "access control" variables?—For Illinois, the estimated coefficients for "access control partial versus none" and "access control full versus none" were 0.3723 and 0.4546, respectively. This implies that for any road section, the tighter the access control we apply to it, everything else being the same, the higher the accident rate would be, which is unreasonable. Again, to make a better judgment on the reasonableness of this result, functional class, speed limit, access control, and ADT will have to be considered simultaneously. Therefore, more detailed information, such as that mentioned above, will be required.

AUTHORS' CLOSURE

We very much appreciate the interest of the discussant and quite a number of other reviewers of our paper examining the relationship of median width and highway accident rates. Obviously this is a subject area of considerable interest.

The first issue raised by the discussant was that "it is entirely possible that the paved inside shoulder width was associated with the accident rate, not the rest of median width." As pointed out, we did not separate the inside shoulder width from the remainder of the median width in the analyses, primarily because of the difficulty of determining where the median/shoulder "begins" for unpaved shoulders (approximately 43 percent of the data). Although it is an interesting hypothesis, we continue to believe that the effect seen is from the total median width rather than just the paved shoulders. Unfortunately, we are not able to reanalyze the data at this time.

After the question was raised, we reexamined the available Illinois roadlog file. (Utah data were unavailable at this time.) In the first place, as noted above, nearly half of the sections in the study file (43 percent) were not paved (i.e., earth, sod, aggregate, surface treated, or no shoulder). Of those that were paved, virtually all were 8 ft (2.5 m) or less and most often (54 percent of the time) were found on roads with median widths of 64 ft (19.6 m) or greater. Less than 10 percent of the sections with paved inside shoulders had median widths of less than 40 ft (12.3 m), where we also saw significant effects of total width.

In short, we find it hard to imagine in this case that paved inside shoulders could account for the effects found in the analysis. However, it is an interesting hypothesis that could be explored further.

With regard to the question about right shoulder widths, only 3 of 982 Utah sections had right shoulder widths exceeding 15 ft (4.6 m) and none of 1,481 Illinois sections had right shoulder widths exceeding 13 ft (4.0 m).

With regard to the comment that "the estimated coefficients for ADT have an algebraic sign contrary to expectation," we do not see why the result that sections of freeways with higher ADTs have lower accident rates is not acceptable. Whereas lower accident frequencies would not be expected, lower accident rates may be. Is it not conceivable that sections with a higher ADT may have slower traffic speeds due to congestion, for example? It should be noted that the number of lanes is the same for all sections in this analysis, meaning higher ADT sections are more congested by definition.

The discussant notes that "the estimated regression coefficients for 'median width' have very low *t*-statistics, indicating that the effect of median width on accident rate was poorly determined from the data." The individual *t* statistics for the median width terms are not especially relevant to whether median width has an effect. Overall, the effect of median width is significant. However, we agree that we could be more sure of the shape of the trend if the individual coefficients were significant as well. Note that median width was examined in greater detail (i.e., quadratic, cubic, and quartic functions) than other variables because it was the primary variable under investigation in this study.

Finally, the problem of collinearity is discussed in the section on statistical methods starting with the paragraph that begins with "Many of the variables included in the regression model were correlated with median width. . ." The available data do not allow clear resolution of the problem. Interactions representing the simultaneous effect of two variables at a time were investigated, but, as stated in the paper, none were found to be significant. Simultaneously cross-classifying sections by median width, functional class, speed limit, access control and ADT is not practical because there would be too few sections in each cell of such a cross-classification. The regression approach adopted appears to be the only practical method of adjusting for other variables in this case.

Again, we appreciate these thoughtful comments and suggestions by the discussant and others and believe that the paper has generally addressed them to the extent practicable with the available data.

Publication of this paper sponsored by Committee on Operational Effects of Geometrics.

Appendix C

Improved Guidelines for Median Safety

Project No. 17-14(2) **COPY NO.____**

IMPROVED GUIDELINES FOR MEDIAN SAFETY

DRAFT REPORT OF ANALYSIS FINDINGS

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
National Research Council

BMI•SG
Vienna, VA 22182

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DISCLAIMER

This is an uncorrected draft as submitted by the research agency. The opinions and conclusions expressed or implied in the report are those of the research agency. They are not necessarily those of the Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, or the individual states participating in the National Cooperative Highway Research Program.

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ABSTRACT

This document describes the analytical findings that were used to evaluate median safety. Cross-section, roadway inventory, and median-involved crash data from California, Iowa, North Carolina, and Ohio were used to perform the analysis. Crash frequency models of median-involved crashes in California, North Carolina, and Ohio are included as is a crash frequency model of cross-median crashes on divided highway in North Carolina. Also, an empirical Bayes' before-after study of median-involved crashes along sections of divided highway in Iowa was conducted. This analysis was performed to determine the effects of median cross-slope flattening on crash experience. Lastly, descriptive measures of crash severity were calculated to provide useful median design and safety trade-off information. The data used for the analysis as well as the analysis results are included in this report.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

The American Association of State Highway and Transportation Officials' (AASHTO) *Policy on Geometric Design of Highways and Streets (1)* and *Roadside Design Guide (2)* contain information that is used to design and protect medians on divided highways. Much of the information contained in these policies is based on data that do not reflect the current design and operating environment. Further, there is a concern among transportation professionals that narrow medians without barrier do not adequately prevent vehicles from crossing the median.

Figure 1 shows the current AASHTO median barrier warrant criteria for high-speed, divided highways with access control. As shown in the figure, the need for median barrier is evaluated if the average daily traffic (ADT) is greater than 20,000 vehicles per day and the median is 0 to 20 feet wide. When traffic volumes exceed 30,000 vehicles per day and the median width is less than 30 feet wide, the need for median barrier is also evaluated. Between 30 and 50 feet, regardless of the five-year projected traffic volume, median barrier is considered optional. When the median width exceeds 50 feet, longitudinal median barrier is not normally considered.

The median barrier warrant criteria shown in Figure 1 have remained unchanged for more than 30 years. Projected traffic volumes and median width are the two observable characteristics that practitioners use to assess median barrier placement. Other guidance provided by AASHTO *(1)* suggests that widths range from 4- to 80-feet or more. In rural areas, median widths between 50- to 100-feet are recommended. Narrow medians are much more common in urban areas. On urban freeways, a minimum of 10-feet is recommended for medians to provide for inside shoulders and placement of a median barrier.

Median slopes are designed to provide adequate drainage channels to convey storm runoff between opposing directions of travel, and to provide a traversable recovery area for errant vehicles that leave the roadway to the left of the traveled way. Side slopes of 6:1 (6 horizontal:1 vertical) or flatter are recommended by AASHTO policy *(1)*. Steeper slopes (e.g., 4:1) may be adequate. Slopes flatter than 6:1 are often required when placing longitudinal median barrier on a slope.

The *Roadside Design Guide (2)* provides median barrier type and placement guidelines. Longitudinal systems that separate opposing travel directions may be flexible, semi-rigid, or rigid. Regardless of the barrier type installed, design deflection distance must be considered for placement. Additionally, median side slopes must too be considered when considering barrier placement locations.

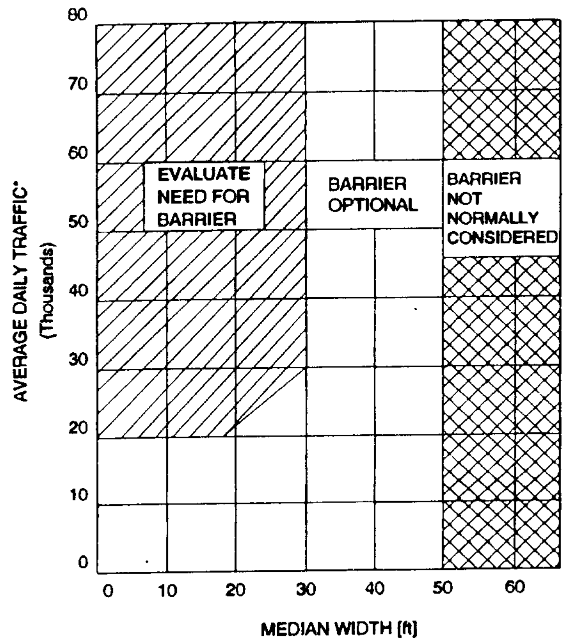

Figure 1. AASHTO Median Barrier Warrant Criteria *(2)*

The objective of this research is to develop improved guidelines for the use of median barriers and for the selection of median widths and slopes on newly constructed and re-constructed high-speed, divided highways. To accomplish the objectives, a survey of State Transportation Agencies (STAs) was distributed to gather information on the current policies and procedures of highway agencies with respect to median design and safety practices. Roadway inventory, crash, and field data were collected and analyzed using various regression procedures. The end product of the research effort is revised median barrier warrant criteria and a guide to median design that considers traffic volumes, median width, median side slopes, median barrier type, and barrier placement guidelines.

BACKGROUND

This section is organized into three parts. Current AASHTO median design and safety policies are described in the first section. The second section is an historical review of relevant median safety literature based on empirical research. The third part is a review of State Transportation Agency (STA) median barrier warrant criteria. Highlighted are those STAs with criteria that differ significantly from AASHTO policy. These STAs were identified through a questionnaire that was administered as part of the project.

Existing Median Design and Safety Practices

This section describes the guidance outlined by AASHTO polices regarding median width, median side slopes, approved median barriers, and median barrier placement guidelines.

Median Width

The median width is a linear dimension between the edges of the traveled way on divided highways, including the left shoulders. Functionally, medians are intended to separate opposing traffic, provide a space for emergency stopping, provide a recovery area for out-of-control vehicles, allow space for speed changes and storage of left-turning and U-turning vehicles, minimize headlight glare, and provide width for future lanes *(1)*. Medians may be raised, flush, or depressed. General guidance suggests that median widths should range between 4- and 80-feet (1.2 and 24 meters). Depressed medians are generally suggested on freeways. Widths greater than 40-feet (12 meters) provide drivers with a sense of separation from the traffic traveling in the opposing lanes *(1)*.

Median widths between 50- and 100-feet (15 and 30 meters) are common on rural freeways. Such a dimension is easily achievable in areas with level terrain with no right-of-way restrictions and where alignments are often parallel. In rural areas with rolling terrain, independent vertical profiles are commonly used to blend the freeway into the environment. Again, wide median widths are achievable. Narrow median widths (10- to 30-feet [3 to 9 meters]) may be needed in mountainous terrain or where right-of-way restrictions dictate.

Medians in urban areas should be as flat and wide as practical; however, right-of-way restrictions or high construction costs commonly establish the limits of median width. On four-lane freeways, AASHTO *(1)* policy suggests a minimum median width of 10-feet (3 meters) for the provision of two 4-foot (1.2 meter) shoulders and a 2-foot (0.6-meter) median barrier. For urban freeways with three or more travel lanes per direction, the AASHTO policy *(1)* suggests a minimum 22-foot (6.6 meter) median with 26-feet (7.8 meters) considered desirable when the directional design hourly volume for truck traffic exceeds 250 vehicles per day.

In certain instances the median width guidelines set forth in the AASHTO policy *(1)* may not be obtainable. Alternatively, the guidelines may be followed by practitioners and cross-median crashes may occur frequently. In either case, median barriers are used to prevent cross-median crashes at narrow median sites. Median barrier warrant criteria are provided in the *Roadside Design Guide (2)* and are considered for application based on combinations of median width and average daily traffic volumes. These criteria are shown in Figure 1.

Median Side Slopes

Median slopes are designed to provide adequate drainage channels to convey storm runoff between opposing directions of travel, and to provide a traversable recovery area for errant vehicles that leave the roadway to the left of the travel lanes. To accomplish these objectives, the AASHTO policy *(1)* recommends 6:1 (6H:1V) side slopes. Steeper slopes (e.g., 4:1) may be adequate. Slopes flatter than 6:1 are often required when placing longitudinal median barrier on a slope.

Median Barrier Types

Longitudinal median barriers may be rigid, semi-rigid, or flexible. Rigidity is measured in terms of the barriers design deflection distance upon vehicle impact. Table 1 shows the median barriers that are most commonly used in the United States. Additionally, the design deflection of the barrier and recommended placement and use guidelines for each median barrier are shown in Table 1.

Table 1. Median Barrier Types and Placement Recommendations.

Barrier Type	Design Deflection	Recommended Site Conditions	Other Notes
Flexible Median Barrier Systems			
Weak-post, W-beam	7 feet (2.1 m)	Flat, traversable slopes	• Can remain effective after struck • Sensitive to mounting height • Requires proper end anchorage
Three-strand Cable	12 feet (3.5 m)	Flat, traversable slopes	• Inexpensive installation • Requires proper end anchorage • Ineffective after being struck • Expensive to maintain
Semi-Rigid Median Barrier Systems			
Box-beam	5.5 feet (1.7 m)	Flat, traversable slopes	• Posts are designed to breakaway at impact • Posts must be repaired after being struck
Blocked-out W-beam (strong post)	2 to 4 feet (0.6 to 1.2 m)	Median width of 10 feet or greater	• Can remain effective after impact • May require rub-rail • Higher impact forces than flexible systems
Blocked-out Thrie-beam (strong post)	1 to 3 feet (0.3 to 0.9 m)	Requires effective barrier height	• Can accommodate larger range of vehicles than w-beam • No need for rub-rail • Higher impact forces than flexible systems
Modified Thrie-beam	2 to 3 feet (0.6 to 0.9 m)	Requires effective barrier height	• Can accommodate larger range of vehicles • Does not usually require immediate repair • Higher impact forces than flexible systems
Rigid Median Barrier Systems			
Concrete Median Barrier	0 feet	Use in narrow, symmetric medians	• Low life-cycle costs • Effective performance • Maintenance-free • High impact forces • High installation cost

Generally, flexible median barrier systems have lower installation costs than semi-rigid or rigid systems. Flexible systems usually require greater maintenance costs than more rigid systems. Also, the impact forces associated with rigid barriers are much greater than those associated with flexible barriers.

Median Barrier Placement Guidelines

In level terrain, symmetric medians are commonplace. In rolling or mountainous terrain, however, asymmetric medians may be constructed due to topography or environmental constraints. Guidelines for placing median barrier in these cross-sections are provided by AASHTO -- Figure 2 shows the AASHTO guidelines for median barrier placement in non-level medians. Section I of Figure 2 shows guidelines for depressed medians; Section II shows placement illustrations for medians with significant traveled way elevation differences; and, Section III illustrates raised median barrier applications.

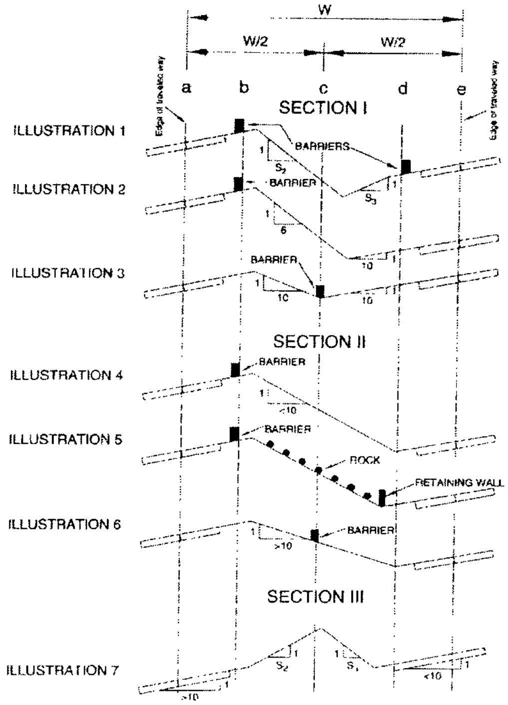

Figure 2. AASHTO Median Barrier Placement Guidelines *(2)*.

The dimensions in Figure 2 are as follows:

- W = median width (feet or meters);
- W/2 = one-half the median width (feet or meters);
- S_2 = left median side slope;
- S_3 = right median side slope; and,
- a, b, c, d, e = median barrier placement locations.

The slopes shown in Figure 2 should first be checked according to roadside safety criteria to determine the need for a roadside barrier. A roadside barrier may be required to prevent errant vehicles from either colliding with a fixed object in the median or to prevent vehicles from overturning when traversing the slope.

Median barriers perform best when the impacting vehicle has all wheels on the ground. When side slopes are flat, longitudinal barriers may be placed in the center of a depressed median. Similarly, rigid objects (e.g., bridge piers or sign supports) may need shielded in the median. Flat slopes are required is such areas and the distance from the barrier to the obstruction should be greater than the barrier's deflection *(2)*. Median barriers with crash cushions are often used to protect obstructions located in a depressed median.

Historical Median Safety Research

Past research on median safety has investigated either the factors that caused vehicle encroachments or median accident relationships. The following section summarizes the history of median safety research by reviewing historical encroachment and accident studies.

Early median safety studies sought to determine and quantify factors that caused vehicle encroachments into the median area on divided highways. In the early 1960's, Hutchinson and Kennedy *(3)* studied vehicle encroachments on two Illinois Interstate highways. There was a sharp decline in the encroachment rate when traffic volumes reach 4,000 to 5,000 vehicles per day. Also, as traffic volumes increased from 2,000 to 6,000 vehicles per day, the encroachment angle increased from 9 to 14 degrees. The percentage of vehicles crossing into the median increased as traffic volumes increased from 4,000 to 6,000 vehicles per day. Lastly, the lateral distance traveled by vehicles encroaching the median increased from 19 to 27 feet (5.8 to 8.3 meters) as traffic volumes increased from 2,000 to 6,000 vehicles per day.

A Canadian *(4)* study of run-off-the-road accidents on a 5.6-mile (9.0 km) section of multi-lane, divided highway revealed the following encroachment information:

- Average roadway departure angle for both median and right-side encroachments was 14 degrees;
- Median encroachments were twice as many as right-side encroachments; and,
- There was a significant disparity between the number of encroachments reported to those observed. The ratio between observed and reported median encroachments was 3 to 1, while the ratio for right-side encroachments was 4 to 1.

A multiple regression model *(4)* revealed that factors such as alcohol, weather, and driver variables were considered to have a significant effect on crash frequency. No correlation between ADT volumes and encroachment rates were found; however, when the data were categorized they nearly matched those of a previously study *(3)*. On average, the ratio of observed to reported accidents was 3.75 to 1 for two-lane undivided highways and 5 to 1 for multi-lane divided highways in Canada.

A study by Garner and Deen *(5)* indicated that accident rate decreases with an increase in the median width up to 30 to 40 feet (9.15 to 12.20 m). At that point, the accident rate remains constant. Deeply depressed medians with 4:1 and 3:1 cross-slopes were shown to have significantly higher accident rates than raised medians or medians with shallow depressions. Additionally, steep median cross-slopes increased the likelihood of vehicle rollover. Garner and Deen *(5)* also concluded that irregular medians with a varying width and nature have higher accident and severity rates.

In 1974, Foody and Culp *(6)* studied the safety aspects between mound and depressed medians in Ohio, each having an 84-foot (25.60 m) design width. A higher accident rate for raised medians was observed. There was no difference in injury-related accidents for the two median design types. There was no difference in the median encroachment frequency for the two design types. Lastly, there was no rollover frequency difference when comparing the two design types.

A more recent study *(7)* showed that median-involved accident rates decrease as the median width increases. Single-vehicle, median-involved accidents in Utah were not shown to decrease with increasing median width. Median-involved accident rates did, however, decrease with increasing median width when evaluating data from Illinois. The most apparent decline in total accident rate on divided highway sections occurred for median widths between 20 feet and 30 feet (6.1 and 9.1 m). For median widths between 60 feet and 80 feet (18.3 and 24.4 m), accident rates remained relatively constant. The crash type most affected by increasing median width was head-on collisions. There was an approximate 17 percent decrease in the relative effects of increasing the median width in 10-foot (3.3 m) increments in Utah. This simply indicates that the head-on crash frequency decreases by 17 percent for each ten-foot increase in median width. Between 10 and 20 feet (3.0 and 6.1 m), there was a 45 percent decrease in the relative effects of increasing the median width in Illinois. From 20 feet to 40 feet (6.1 to 12.2 m), the average decline in relative effects was 42 percent. For median widths greater than 40 feet (12.2 m), the relative effect remained nearly constant.

Mason, et al. *(8)* recently used crash and roadway inventory data to characterize cross-median crashes on Pennsylvania Interstates and expressways. Cross-median crashes were defined as those where a vehicle traveling in one direction on a divided highway, left the roadway to the left, crossed the median, and collided with a vehicle traveling in the opposing travel lanes. Of these crash types, 15 percent were fatal and 72 percent resulted in occupants being injured. When compared to all crash types on Interstates and expressways, the severity level of cross-median crashes was significantly more severe. Limited field data collection found that median shoulder width, roadway grade, median cross-slopes, the presence and degree of horizontal curvature, presence of roadside obstacles, and vehicle type did not statistically influence cross-median crashes.

Donnell *(9)* developed median barrier crash frequency models using Pennsylvania data. Additionally, severity models of cross-median and median barrier crashes were developed. Variables that were found to influence median barrier crash frequency include traffic volume, presence of interchange entrance ramps, posted speed limit, presence and direction of horizontal curvature, and the lateral offset of the barrier from the edge of the travel way. The geometric variables that were found to influence crash severity included the presence of interchange entrance ramps and traffic volumes. The crash frequency and severity models were used in an economic evaluation of Pennsylvania's existing median barrier warrant criteria (same as AASHTO). Results of the research concluded that there is an economic and safety benefit that accompanies revised median barrier warrant criteria. This benefit can be realized when installing median barrier on divided highways that are up to 70-feet wide and have directional daily traffic volumes exceeding 20,000 vehicles per day, if the barrier is placed in the center of the median. When barrier is placed closer to the travel way, the benefit of placing barrier changes incrementally based on traffic volume and median width.

State Transportation Agency Median Barrier Warrant Criteria

The decision to place median barrier varies among STAs. Those STAs that have median barrier warrant criteria that depart from AASHTO's *(2)* are discussed in this section as are the methodologies that were used to develop the recommended practices. Unique STA criteria are based on either a safety-based study or an economic evaluation.

California

Since 1947, the California Department of Transportation (Caltrans) has periodically reviewed median installations and the effect that they have on accident frequency and severity. A major study performed in 1958 related traffic volumes to median widths, thus establishing a barrier warrant policy. This 1958 study called for barrier consideration on roadways carrying volumes in excess of 60,000 vehicles per day and having median widths less than 36-feet *(10)*. Cable barriers were considered positive protection for median widths between 16- and 36-feet (4.9 and 11.0 m) while metal beam barriers were used in medians less than 16 feet wide. Subsequent evaluations took place, which only confirmed that the barriers were successful in reducing fatal cross-median crashes.

In 1968, Caltrans performed an economic evaluation and concluded that barrier installation should be concentrated at locations with medians up to and including 45-feet (13.7 m) in width *(10)*.

In 1997, Caltrans again conducted a study to their median barrier warrant criteria. The study evaluated the traffic volume/median width warrant as well as an accident study warrant of 0.50 cross-median accidents of any severity per mile per year or 0.12 fatal cross-median accidents per mile per year *(10)*. An economic evaluation was used to assess the volume/median width warrant. Specifically, a benefit/cost analysis was developed that accounted for the increased number of accidents that occurred after installing longitudinal median barrier on divided highways.

The benefit/cost analysis used in the study was based on a human capital method where fatal accidents were valued at $850,000 per accident, injury accidents were valued at $17,200 per accident, and property-damage only accidents were valued at $3,700 per accident. In addition, the cost of installing median barrier on California freeways was valued at $270,000 per mile. To complete the benefit/cost analysis, the severity of hit-barrier accidents versus cross-median accidents was determined. The data collected for the study contained sites where barrier was present (after condition) and where barrier was not present (before condition). Many combinations of median width and average daily traffic were studied, and the results are shown in Figure 3. Ultimately, the benefit/cost ratio determined in relation to extending the volume/width warrant up to 75 feet (22.9 m) was 1.10. In all, this modified warrant required 390 miles (628 km) of newly installed barrier that would provide a reduction of 15 fatal accidents per year, an increase of 320 injury accidents per year, and an increase of 550 property-damage only accidents per year.

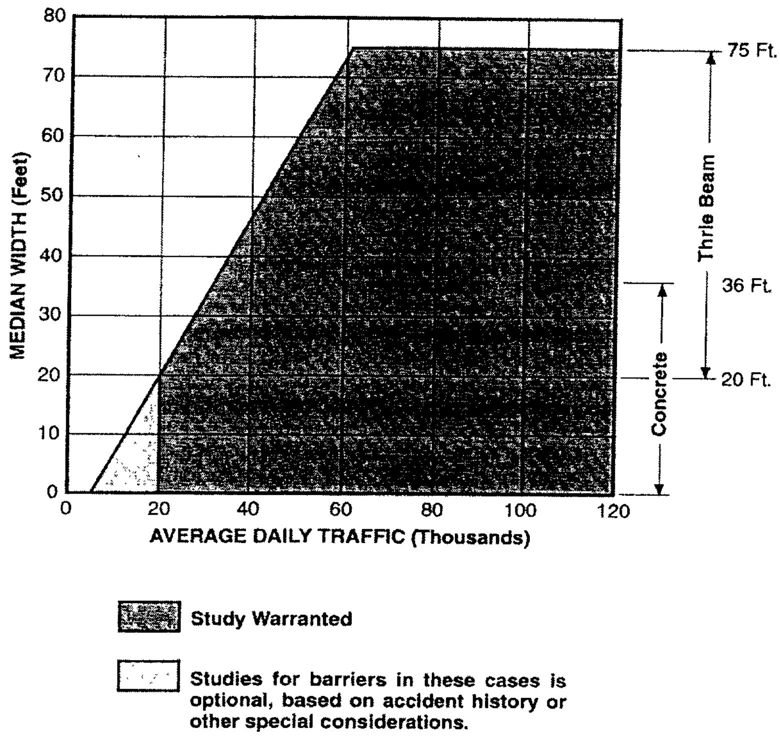

FIGURE 3

Figure 3. California Freeway Median Barrier Warrant *(10)*.

Florida

In 1991, the Florida Department of Transportation adopted the policy of installing longitudinal median barrier on all divided Florida highways if the median width were less than 64-feet (19.5 meters). An examination of cross-median crashes based on five years of crash data (1995 through 1999) was undertaken to determine the typical characteristics of these crashes and to recommend methods to reduce their frequency and severity. During the data collection period, it was estimated that between 300 and 750 cross-median collisions occurred on Florida highways. The following characteristics of cross-median crashes were identified by review of hardcopy police accident reports *(11)*:

- Approximately 19 percent involved or were suspected to involve alcohol.
- About 2 percent of crashes involved a truck as the crossing vehicle.
- Nearly 78 percent of crashes occurred when the crossing vehicle's speed was within five miles per hour of the posted speed limit.
- Prevailing weather conditions were good in 75 percent of crashes – 83 percent of these crashes were the result of driver error and avoidance maneuvers.
- About half of the crashes that occurred during adverse weather conditions involved hydroplaning and the other half were the result of driver error and avoidance maneuvers.
- Approximately 62 percent of all cross-median crashes occurred within one-half mile of interchange ramp termini, and approximately 82 percent occurred within one mile of ramp termini.

A cost-effectiveness analysis revealed that median barriers should reduce the fatality rate and societal costs due to cross-median crashes by about 50 percent; however, the overall crash frequency and injury rates will increase by 600 and 28 percent, respectively. When installed in areas without a crash history, the barrier may not offer any cost benefit over the no-barrier alternative. It was recommended that the 64-foot (19.5 meters) median barrier warrant be retained and the barrier is evaluated based on crash history. Also, crash locations within one mile of ramp termini were investigated and locations with a crash history are being considered for barrier installation.

Maryland

Although the Maryland State Highway Administration defers to the AASHTO *Roadside Design Guide (2)* to determine the need for median barrier on some divided highways, recent crossover crashes required implementation of stricter guidelines on high-speed, full access-controlled highways. In January 2003, *Guidelines for Traffic Barrier Placement and End Treatment Design (12)* was issued as a new standard for median design in Maryland. The document is intended to supplement the AASHTO *Roadside Design Guide (2b)* for design clear zone widths and to determine the need for traffic barrier and end treatments on high-speed highways (design speed greater than 45 mph). Figure 4 shows the median barrier warrant criteria that are used in Maryland to assess the need for median barrier on divided highways with full access control. Based on the figure, the following guidelines were developed for using median barrier on divided highways:

- Medians less than or equal to 30-feet with daily traffic volumes greater than zero;
- Medians less than or equal to 50-feet with daily traffic volumes greater than 40,000 vehicles per day; and,
- Median less than or equal to 75-feet with daily traffic volumes greater than 80,000 vehicles per day.

Divided highway sections with traffic volume and median width combinations beyond those in the hatched area of Figure 4 may require median barrier due to accident history.

New Hampshire

New Hampshire typically considers the installation of median barrier on medians of less than 50-feet (15 meters) wide. In 1991, the transportation department performed an internal study utilizing the ROADSIDE program from the 1989 AASHTO *Roadside Design Guide (2b).* The study analyzed collision frequencies for median widths of 26-, 40-, 50-, 60-, and 70-feet, each with average daily traffic volumes of 40,000 vehicles per day. The purpose of the study was to support the environmental impact statement for New Hampshire Route 101. The conclusions from the study were that a 50-foot (15 meter) median is the maximum width that should be considered for installation of longitudinal barrier.

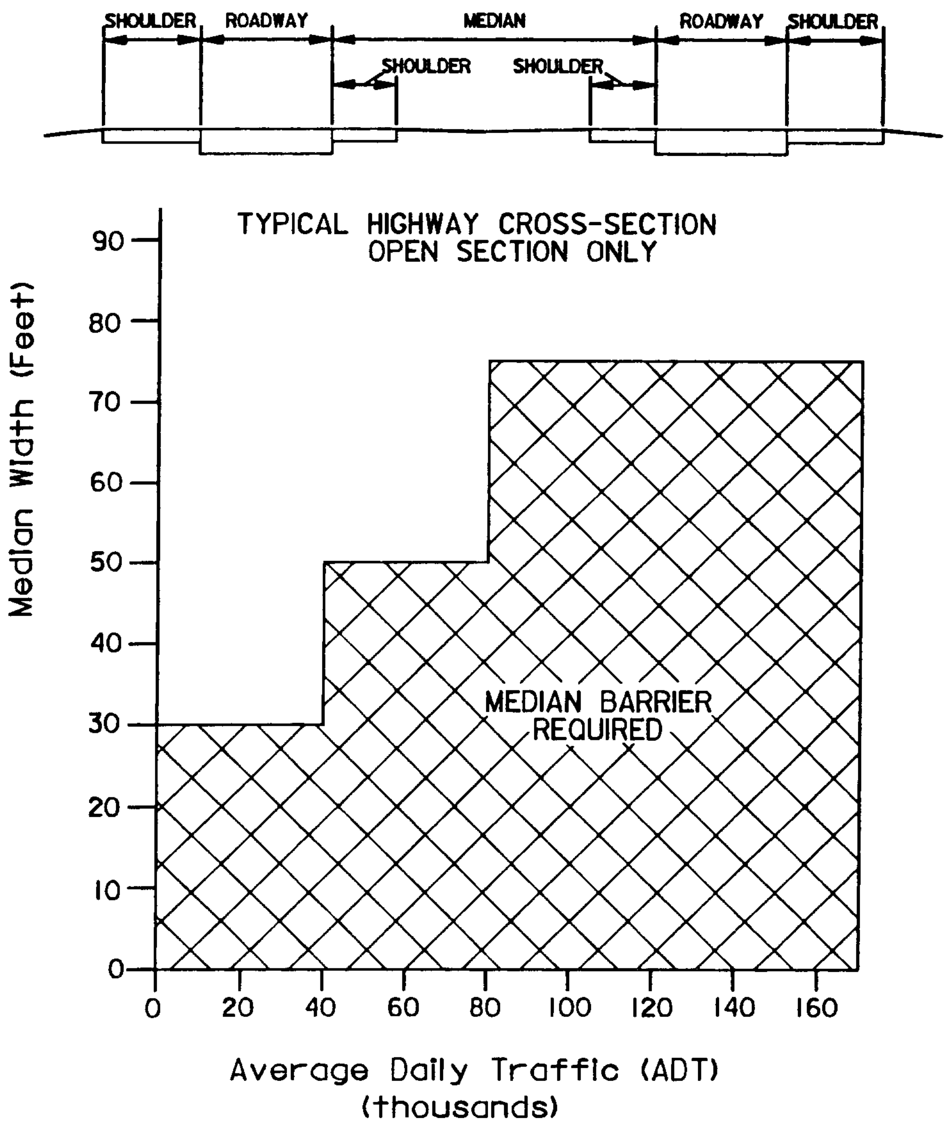

Figure 4. Maryland Median Barrier Warrant Criteria *(12)*

North Carolina

Population growth in North Carolina has spawned an increase in the number of vehicle-miles traveled. This increase in travel is also associated with an increase in cross-median crashes on the interstate and expressway system. The *Across Median Safety Study (13)* identified and investigated over 800 median cross-over crashes along nearly 1,375 miles (2,214 kilometers) of interstate and non-interstate freeway facilities in North Carolina from 1994 through 1997. The study showed that although cross-median crashes make-up less than five percent of the injuries on the system considered, these crashes comprise nearly 23 percent of all fatal injuries and 13 percent of all severe injuries *(13).* When considering AASHTO's median barrier warrant criteria, only 27 percent of all cross-median crashes on North Carolina freeways occur where a barrier is warranted; 58 percent occur where barrier is optional; 15 percent occur where barrier is not normally considered. The across median crash data are shown in Figure 5 with the AASHTO warrants indicated.

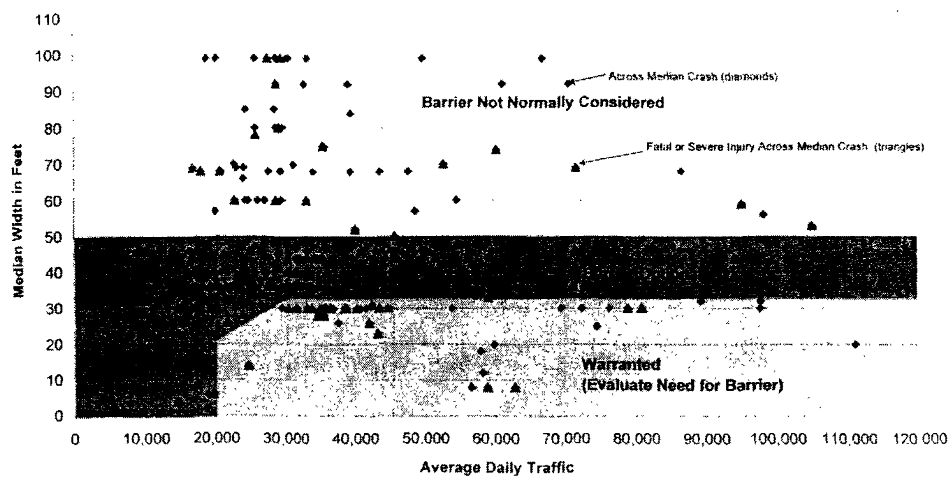

Figure 5. Cross Median Crashes on North Carolina Divided Freeways *(13)*.

In 1998, North Carolina Department of Transportation initiated a proactive approach to prevent across median crashes. The first phase of the plan identified 23 high-priority locations along 240 miles (386 kilometers) of freeway where cross-median crashes represented an unusually high concentration of accidents. It was recommended that some type of positive barrier protection be installed immediately in these locations to prevent further accidents. The second phase of the plan consisted of prioritizing and systematically protecting all freeway sections with median widths less than 70 feet (21.3 m). A hazard index that linked average daily traffic (ADT), speed limit, and median widths was developed to help create a priority ranking system. In all, over 100 additional sections were identified as potential protection locations. The final phase of the plan consisted of revising the state's median design policy so that no more freeways could be built with median widths less than 70 feet *(13)*.

Of the 23 locations that were identified in phase one of the plan, the total estimated cost of installing some type of positive barrier was nearly $16 million; the 100 locations that were subsequently identified for protection in phase two of the plan could cost an additional $65 million based on an estimated $80,000 per mile unit cost *(13)*.

Washington

The purpose of a Washington State Department of Transportation study *(14)* was to evaluate the frequency and severity of cross-median crashes on divided highways. A benefit-cost analysis was used to develop revised median barrier installation guidelines and to rank or prioritize median barrier improvement projects. In all, 677 miles (1,083 kilometers) of Washington State highways were studied. Each section examined was a multi-lane, divided highway with full control of access and with a depressed or unprotected median. Additionally, posted speed limits were greater than 45 miles per hour (72 kilometers per hour) and average daily traffic volumes were greater than 5,000 vehicles per day. Five years of crash data (1996 through 2000) were examined and a total of 642 cross-median crashes identified. Prior to the research, the AASHTO median barrier warrant criteria were used to evaluate the need for median barrier.

Crash analysis produced the following descriptive measures:

- Three cross-median crashes in five years at highway locations with 0- to 30-foot medians (0 to 9 meters);
- 273 crashes at locations with 31- to 40-foot medians (9.5 to 12 meters);
- 100 crashes at locations with 41- to 50-foot medians (12.5 to 15 meters);
- 9 crashes at locations with 51- to 60-foot medians (15.5 to 18 meters);
- 16 crashes at locations with 61- to 70-foot medians (18.5 to 21 meters);
- 153 crashes at locations with 71- to 80-foot medians; (21.5 to 24 meters) and,
- 88 crashes at sites with medians wider than 80-feet (24 meters).

A benefit-cost analysis was used to develop a revised median barrier warrant. Benefits were derived from the reduction in crash severity as a result of median barrier installation. It was assumed that the frequency of crashes in sections without median barrier would equal the number of crashes after a barrier was installed. The assumed crash severity after barrier installation was "possible injury." Based on the analysis, there was a clear indication that the installation of median barrier offered benefits that exceeded costs for medians up to 50-feet (15 meters) in width, regardless of the barrier type being installed. This resulted in a policy change by the Washington State Department of Transportation. Currently, median barrier is recommended on all full-access controlled, multi-lane highways with posted speeds greater than 45-feet (13.7 meters) if the median is less than 50-feet (15 meters) wide. The barrier type is determined on a project basis and medians with lower posted speeds or with widths greater than 50-feet (15 meters) are considered as candidate median barrier locations based on crash histories.

CROSS-MEDIAN CRASH ANALYSIS

A cross-median crash analysis was performed using only data from North Carolina. Table 2 shows descriptive measures of the crash and roadway inventory data for the sample of North Carolina cross-median crashes. The categorical variable for the elevation difference between opposing directions of travel contained 301.4 miles of divided highway with a symmetric median (or no elevation difference). There were 83.6 miles of divided highway where the opposing travel directions had an elevation difference of less than 5-feet; and, there were 16.9 miles of divided highway where the opposing travel directions differed in elevation by more than 5-feet.

Table 2. North Carolina Cross-Median Crash Variables.

Variable Name	**Description**	**Variable Type**	**Descriptive Measures**		
			Min	**Max**	**Avg**
TXMED	Number of cross-median crashes per year per highway section	Count (Response)	0	9	0.15
SEG_LNG	Segment length (miles)	Continuous	0.1	4.7	0.5
AADT	Average annual daily traffic (vehicles per day)	Continuous	2,002	128,300	31,245
OP_PAVSHD	Opposite side paved shoulder width (feet)	Continuous	1	33	4.9
OP_SLOP	Opposite side median slope (percent)	Continuous	-25.4	14.8	-8.1
OP_SLNG	Opposite side median slope length (feet)	Continuous	5	103	25.4
AD_PAVSHD	Adjacent side paved shoulder width (feet)	Continuous	1	21	4.7
AD_SLOP	Adjacent side median slope (percent)	Continuous	-25.4	12.9	-8.0
AD_SLNG	Adjacent side median slope length (feet)	Continuous	5	103	25.4
MEDWID	Median width (feet)	Continuous	11	219	51.0
ELEV	Elevation difference between opposing travel directions	Categorical	1: None 2: Less than 5-foot difference 3: Greater than 5-foot difference		

Figure 6 is a scatter plot of cross-median crash events based on median width and average daily traffic volumes. The current AASHTO median barrier warrant criteria are also shown in Figure 6. Based on the data, approximately 34.8 percent of cross-median crashes occurred on highway sections that fall within the region labeled "Evaluate the Need for Barrier" based on existing AASHTO guidelines. About 32.2 percent and 33.0 percent of cross-median crashes in North Carolina occurred on highway sections that fall within the regions labeled "Barrier Optional" and "Barrier Not Normally Considered", respectively, based on existing AAHSTO design criteria.

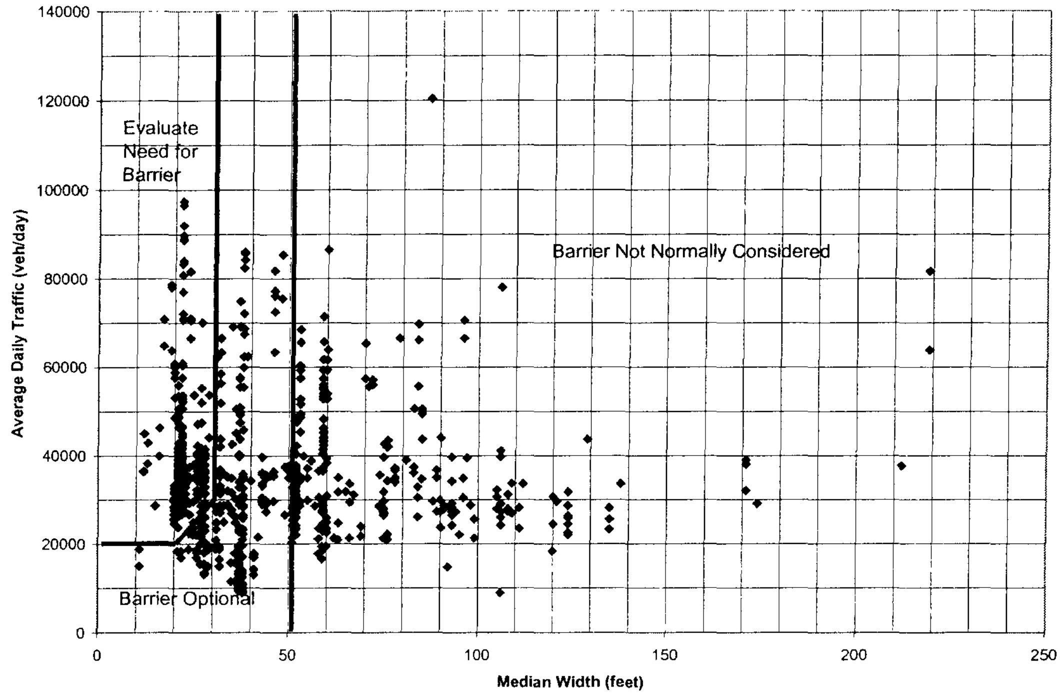

Figure 6. Scatter Plot of North Carolina Cross-Median Crashes

Predictive Modeling Results

The first model developed, using negative binomial regression, included all of the predictor variables shown in Table 2. Results from this initial analysis are shown in Table 3. Exploratory analysis revealed that the most appropriate general model form is that which is shown in Equation 1.

Equation 1

$$N_{CMC} = e^{\beta_1} \bullet L^{\beta_2} \bullet ADT^{\beta_3} \bullet \exp(\beta_4 X_4) \bullet \ldots \bullet \exp(\beta_k X_k)$$

where: N_{CMC} = expected number of cross-median crashes per year;

β's = regression parameters estimated from the model;

L = section length (miles);

ADT = average daily traffic (vehicles per day);

X's = cross-section explanatory variables.

Table 3. North Carolina Cross-Median Crash Analysis Results.

Parameter	df	Estimate	Standard Error	Confidence Limits		Wald Chi-square	p-value
				Lower	Upper		
Intercept	1	-7.991	0.799	-9.306	-6.677	99.99	<0.0001
ADT (log)	1	0.874	0.074	0.753	0.996	140.38	<0.0001
Length (log)	1	0.835	0.037	0.774	0.896	506.90	<0.0001
Op_pavshd	1	-0.061	0.064	-0.166	0.045	0.88	0.347
Medwid	1	-0.022	0.007	-0.034	-0.009	8.50	0.004
Ad_slop	1	0.067	0.051	-0.017	0.150	1.71	0.191
Ad_slgn	1	-0.149	0.030	-0.198	-0.099	24.42	<0.0001
Ad_pavshd	1	-0.022	0.067	-0.132	0.089	0.11	0.744
Elev (None)	1	-0.274	0.191	-0.587	0.040	2.07	0.151
Elev (Less than 5 feet)	1	-0.592	0.201	-0.923	-0.262	8.71	0.003
Op_slop	1	-0.059	0.049	-0.139	0.021	1.48	0.223
Op_slng	1	0.106	0.028	0.061	0.152	14.67	0.0001
Ad_slop*ad_slgn	1	-0.009	0.003	-0.014	-0.004	9.63	0.002
Op_slop*op_slng	1	0.011	0.003	0.007	0.016	15.08	0.0001
Medwid*ad_slop	1	0.001	0.001	-0.001	0.004	1.02	0.311
Medwid*op_slop	1	-0.003	0.002	-0.006	-0.001	4.41	0.036
Medwid*ad_slgn	1	0.0003	0.0002	-0.0001	0.0006	1.80	0.180
Medwid*op_slng	1	0.0001	0.0002	-0.0002	0.0004	0.10	0.755
Dispersion	1	0.1434	0.073	0.062	0.331		

Notes:
$\alpha = 0.10$
Number of observations: 7,247
Deviance (value/df): 3,192.37 (0.442)
Pearson chi-square (value/df): 8,878.23 (1.229)

The preliminary analysis results (Table 3) indicate that traffic volume, median width, median cross-slope length, and various interaction terms involving median width, median cross-slope length, and median cross-slope (percent) are all highly significant. There are, however, explanatory variables that are highly correlated and affect the modeling results. For instance, the inside paved shoulder width (ad_pavshd and op_pavshd) for both travel directions are included in the definition of median width. The difference in elevation between the opposing roadways on divided highways (ELEV) is also highly correlated with the median cross-slope and length of cross-slope (ad_slope, op_slop, ad_slng, and op_slng). As a result, the inside paved shoulder width, length of median cross-slope, and elevation difference variables were removed from the analysis. Also, it was hypothesized that revised median barrier warrant criteria be based solely on median width, ADT, and median cross-slopes. A second cross-median crash model was estimated with these variables -- the results are shown in Table 4.

Interpretation of the results shown in Table 4 indicates that 4 of 5 explanatory variables were statistically significant at the 10 percent level. The Pearson chi-square statistic, divided by its degrees of freedom, equals approximately 1.22. The deviance statistic, divided by its degrees of freedom, equals 0.46. The closer these values are to 1.0, the better the model fit. The relative effect of each explanatory variable on the expected number of cross-median crashes can be determined by exp(parameter estimate). In order words, the relative effect of a one unit increase in median width is exp(-0.010), or a one percent reduction in the expected number of cross-median crashes per year. Similarly, a one unit increase in the adjacent slope (ad_slop) results in a 4.6 percent decrease in the expected cross-median crash frequency. A one percent increase in the opposite median cross-slope (op_slop) increases the expected cross-median crash frequency by about 2.8 percent. These results suggest that steeper cross-slopes increase cross-median crashes.

Table 4. Final North Carolina Cross-Median Crash Analysis Results.

Parameter	**df**	**Estimate**	**Standard Error**	**Confidence Limits**		**Wald Chi-square**	**p-value**
				Lower	**Upper**		
Intercept	1	-9.357	0.729	-9.556	-8.158	164.85	<0.0001
ADT (log)	1	0.841	0.071	0.725	0.958	141.95	<0.0001
Length (log)	1	0.897	0.038	0.835	0.960	556.45	<0.0001
Medwid	1	-0.010	0.002	-0.012	-0.008	43.52	<0.0001
Ad_slop	1	-0.047	0.022	-0.083	-0.011	4.59	0.032
Op_slop	1	0.028	0.021	-0.006	0.063	1.79	0.181
Dispersion	1	0.221	0.090	0.113	0.431		

Notes:
$\alpha = 0.10$
Number of observations: 7,242
Deviance (value/df): 3,306.23 (0.460)
Pearson chi-square (value/df): 8,817.87 (1.219)

Interpretation of Results

Based on the descriptive median safety measures and the predictive modeling efforts, it is clear that median width and traffic volumes affect the frequency of cross-median crashes. Further, there is also statistical evidence the median cross-slopes influence the frequency of cross-median crashes. A discussion of cross-median crash severity is presented later in this report; however, it is clear from that discussion that a logical dichotomy of median cross-slopes should be those slopes that are 6:1 or steeper and those that are flatter than 6:1. It is also evident that the adjacent median cross-slope has a greater impact on cross-median crash frequency, thus another model with a categorical variable for median cross-slope was estimated to assist with interpretation of the results. This model contained only the section length, ADT, median width, and adjacent median cross-slope variables. Equation 2 below is the resulting model output – the model fit and parameter estimates were very similar to those presented in Table 4.

Equation 2

$$N_{CMC} = e^{-9.476} \bullet ADT^{0.867} \bullet L^{0.896} \bullet \exp(-0.010MW) \bullet \exp(0.028AS)$$

where: N_{CMC} = frequency of cross-median crashes per year;

ADT = average daily traffic (vehicles per day);

L = section length (miles);

MW = median width (feet);

AS = adjacent median cross-slope (1 if flatter than 6:1; 0 otherwise).

Tables 5 and 6 show the expected cross-median crash frequency based on Equation 2.

Table 5. Expected Cross-Median Crash Frequency in North Carolina
(Median Cross-Slopes Flatter than 6:1).

ADT (vpd)	Median Width (feet)										
	0	10	20	30	40	50	60	70	80	90	100
10000	0.2191	0.1976	0.1783	0.1608	0.1451	0.1309	0.1181	0.1065	0.0961	0.0867	0.0782
20000	0.3995	0.3604	0.3251	0.2933	0.2646	0.2387	0.2154	0.1943	0.1753	0.1581	0.1426
30000	0.5678	0.5123	0.4621	0.4169	0.3761	0.3393	0.3061	0.2761	0.2491	0.2247	0.2027
40000	0.7287	0.6574	0.5930	0.5350	0.4826	0.4354	0.3928	0.3543	0.3197	0.2884	0.2601
50000	0.8842	0.7977	0.7196	0.6492	0.5856	0.5283	0.4766	0.4300	0.3879	0.3499	0.3157
60000	1.0356	0.9343	0.8428	0.7603	0.6859	0.6188	0.5582	0.5036	0.4543	0.4098	0.3697
70000	1.1837	1.0679	0.9634	0.8691	0.7840	0.7073	0.6381	0.5756	0.5193	0.4684	0.4226
80000	1.3290	1.1989	1.0816	0.9757	0.8802	0.7941	0.7164	0.6463	0.5830	0.5259	0.4745
90000	1.4719	1.3278	1.1979	1.0806	0.9749	0.8795	0.7934	0.7157	0.6457	0.5825	0.5255
100000	1.6127	1.4549	1.3125	1.1840	1.0681	0.9636	0.8693	0.7842	0.7074	0.6382	0.5757

Based on the existing AASHTO median barrier warrant criteria, the need for barrier should be evaluated when the ADT is greater than 20,000 vehicles per day and the median is more than 20-feet wide. The need for median barrier should also be evaluated when the ADT is greater than 30,000 vehicles per day and the median is more than 30-feet wide. Based on the existing guidelines, the minimum expected number of cross-median crashes per mile per year is 0.3251 for the combination of ADT and median width of 20,000 vehicles per day and 20-feet wide, respectively. Using the expected cross-median crash frequency as the sole measure of median safety, this would indicate that all expected frequencies greater than 0.3251 in Table 5 be included in the "Evaluate Need for Barrier" region of revised median barrier warrant criteria. A similar interpretation of the expected cross-median crash frequency can be conducted using the data presented in Table 6.

Table 6. Expected Cross-Median Crash Frequency in North Carolina (Median Cross-Slopes 6:1 or Steeper).

ADT (vpd)	Median Width (feet)										
	0	10	20	30	40	50	60	70	80	90	100
10000	0.2252	0.2032	0.1833	0.1654	0.1492	0.1346	0.1214	0.1095	0.0988	0.0891	0.0804
20000	0.4108	0.3706	0.3343	0.3016	0.2721	0.2454	0.2214	0.1998	0.1802	0.1626	0.1467
30000	0.5838	0.5267	0.4751	0.4286	0.3867	0.3488	0.3147	0.2839	0.2561	0.2310	0.2084
40000	0.7492	0.6759	0.6097	0.5501	0.4962	0.4477	0.4038	0.3643	0.3287	0.2965	0.2675
50000	0.9091	0.8202	0.7399	0.6675	0.6021	0.5432	0.4900	0.4421	0.3988	0.3598	0.3246
60000	1.0648	0.9606	0.8666	0.7818	0.7053	0.6362	0.5740	0.5178	0.4671	0.4214	0.3802
70000	1.2171	1.0980	0.9905	0.8936	0.8061	0.7272	0.6560	0.5918	0.5339	0.4817	0.4345
80000	1.3665	1.2327	1.1121	1.0032	0.9051	0.8165	0.7366	0.6645	0.5994	0.5408	0.4878
90000	1.5134	1.3653	1.2317	1.1111	1.0024	0.9043	0.8158	0.7359	0.6639	0.5989	0.5403
100000	1.6582	1.4959	1.3495	1.2174	1.0982	0.9907	0.8938	0.8063	0.7274	0.6562	0.5920

Using the expected cross-median crash frequency as the sole measure of median safety, this would indicate that all expected frequencies greater than 0.3343 in Table 6 be included in the "Evaluate Need for Barrier" region of revised median barrier warrant criteria. When comparing the results of Tables 5 and 6, there is little support for dichotomizing the median cross-slope. The expected cross-median crash frequency varies little when comparing the tables and, furthermore, the shape of revised median barrier warrant criteria would not change.

CHAPTER II

FINDINGS

MEDIAN-INVOLVED CRASH ANALYSIS

This section of the report is subdivided into a discussion of median-involved crash analysis for divided, traversable highway sections with no longitudinal median barrier, for divided highway sections that are non-traversable, and for sections that contain median barrier.

Traversable Sections with No Longitudinal Median Barrier

This section is divided into a discussion of the data and resulting median-involved crash frequency analysis using data from California, North Carolina, and Ohio.

California

The data used to develop the median-involved crash prediction model are shown in Table 7. Negative binomial regression was again used to develop the median-involved crash frequency model. Exploratory analysis revealed that the most appropriate general model form is that which is shown in Equation 1.

Table 7. California Median-Involved Crash Variables
(Traversable Sections with No Median Barrier, 1997 - 1999).

Variable Name	Description	Variable Type	Descriptive Measures		
			Min	Max	Avg
Crashes	Number of median-involved crashes per year per mile	Count (Response)	0	60	5.8
Length	Segment length (miles)	Continuous	0.1	62.2	4.5
AADT	Average annual daily traffic (vehicles per day)	Continuous	8,132	192,674	32,730
AdjSlope	Adjacent side median slope (percent)	Continuous	-28.0	20.0	-4.8
AdjSlopeLength	Adjacent side median slope length (feet)	Continuous	0	74	30.0
OppSlope	Opposite side median slope (percent)	Continuous	-30.0	26.0	-4.9
OppSlopeLength	Opposite side median slope length (feet)	Continuous	0	102	28.7
MW	Median width (feet)	Continuous	10	138	57.4

The distribution of median-involved crashes for divided, traversable California roadway segments with no barrier is shown in Figure 7. As shown, approximately 22.9 percent of the roadway segments in the California data set experienced no median-involved crashes in a three-year period. More than 12 percent of the sections experienced a single median-involved crash during the three-year analysis period. About 11 percent of sections had two crashes during the analysis period.

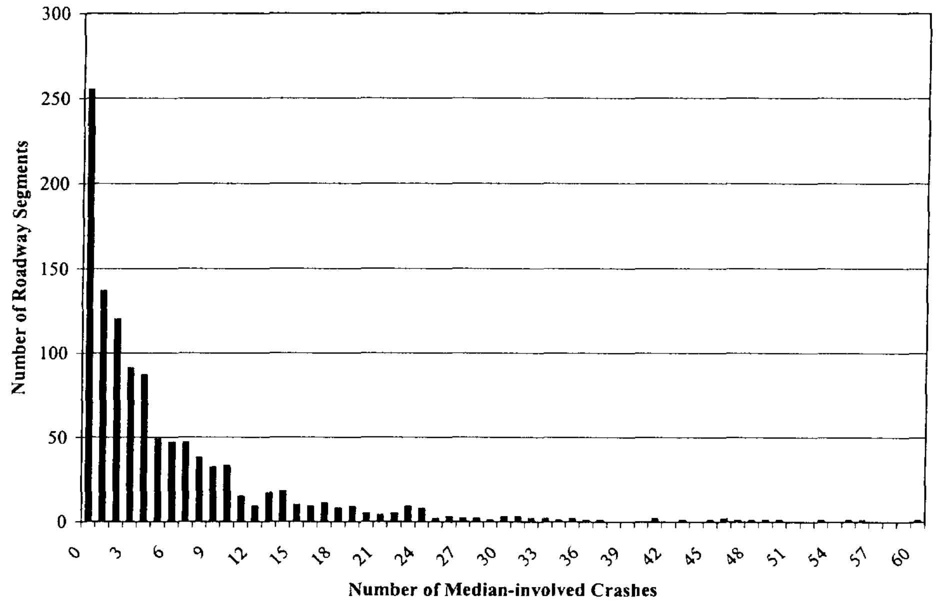

Figure 7. California Median-Involved Crash Distribution (Traversable Sections with No Barrier).

Figure 8 is a scatter plot of median-involved crashes on traversable, divided highway sections in California. Based on the data, 6.6 percent of median-involved crashes occur in the region of the AASHTO median barrier warrant figure labeled "Evaluate Need for Barrier." Approximately 41.7 percent and 52.3 percent of median-involved crashes occurred on highway sections that fall within the regions labeled "Barrier Optional" and "Barrier Not Normally Considered", respectively, based on existing AAHSTO design criteria.

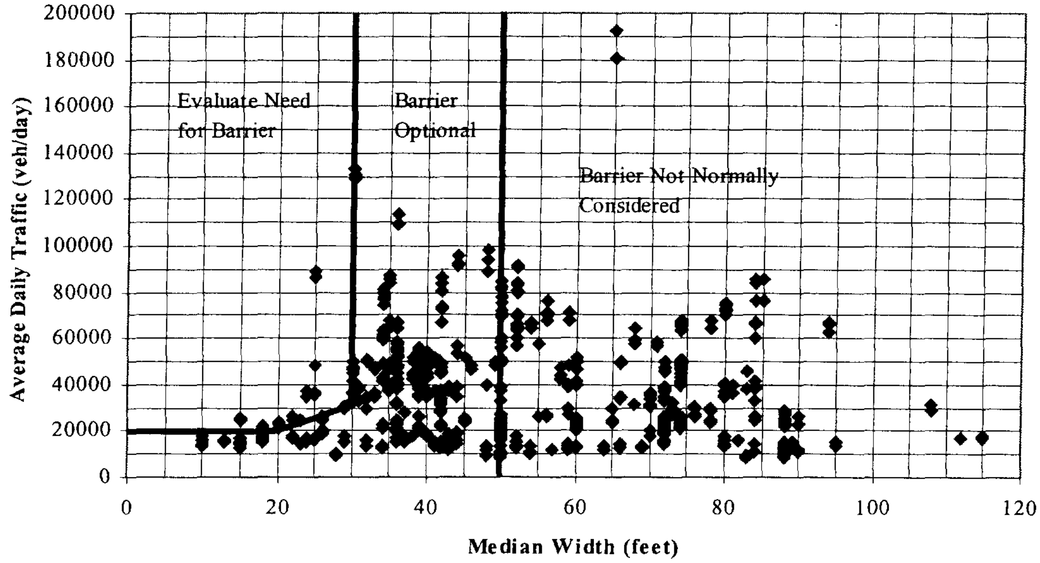

Figure 8. Scatter Plot of California Median-Involved Crashes

Predictive Modeling Results. A preliminary analysis with all explanatory variables (Table 8) shows that traffic volume, median width, opposing median cross-slope length, and various interaction terms involving median width, median cross-slope length, and median cross-slope (percent) are all highly significant.

The Pearson chi-square statistic, divided by its degrees of freedom, equals approximately 0.90. The deviance statistic, divided by its degrees of freedom, equals approximately 1.11. The closer these values are to 1.0, the better the model fit. The relative effect of each explanatory variable, leaving all other variables constant, on the expected number of median-involved crashes can be determined by exp(parameter estimate). In order words, the relative effect of a one unit increase in median width is exp(-0.016), or a 1.6 percent reduction in the expected number of median-involved crashes per year. A one unit increase in the adjacent median cross-slope (adjslope) results in a 1.8 percent increase in the expected median-involved crash frequency on divided highways in California. A one unit increase in the opposing slope (oppslope) results in a 3.0 percent decrease in the expected median-involved crash frequency. Both the adjacent and opposite median cross-slope length have a minimal effect on the expected median-involved accident frequency. All of the interaction terms also have a minimal relative effect on median-involved crash experience.

Table 8. California Median-Involved Crash Analysis Results
(Traversable Sections with No Longitudinal Barrier).

Parameter	**df**	**Estimate**	**Standard Error**	**Confidence Limits**		**Wald Chi-square**	**p-value**
				Lower	**Upper**		
Intercept	1	-9.872	0.496	-10.688	-9.056	395.71	<0.0001
AADT (log)	1	1.021	0.045	0.947	1.100	511.56	<0.0001
Length (log)	1	0.850	0.025	0.810	0.890	1206.35	<0.0001
MW	1	-0.016	0.006	-0.025	-0.007	7.90	0.005
AdjSlope	1	0.018	0.025	-0.024	0.060	0.51	0.474
AdjSlopeL	1	0.014	0.006	0.004	0.023	5.65	0.018
OppSlope	1	-0.030	0.021	-0.065	0.005	1.93	0.164
OppSlopeL	1	0.012	0.006	0.003	0.021	4.88	0.027
AdjSlope*AdjSlopeL	1	0.001	0.001	-0.001	0.001	0.94	0.333
OppSlope*OppSlopeL	1	-0.001	0.001	-0.001	0.000	3.01	0.083
MW*AdjSlope	1	-0.001	0.001	-0.001	0.000	4.10	0.043
MW*OppSlope	1	0.001	0.001	0.001	0.001	3.46	0063
Dispersion	1	0.415	0.029	0.370	0.466		

Notes:
$\alpha = 0.10$
Number of observations: 1,107
Deviance (value/df): 1,211.105 (1.106)
Pearson chi-square (value/df): 984.312 (0.899)

The previous model contains some explanatory variables that are correlated, namely the median cross-slope length (adjslopel and oppslopel) and median width. As a result, another model was estimated using only ADT, median width, and adjacent and opposite median cross-slope as explanatory variables. These results are shown in Table 9 below. Interpretation of the results is the same as discussed previously. Based on the results, a one unit increase in the median width (holding all other explanatory variables constant) decreases the expected cross-median crash frequency by less than one percent. A one unit increase in the adjacent median cross-slope decreases the expected crash frequency by nearly 1.4 percent, thus suggesting that steeper median cross-slopes, adjacent to the travel lanes, increases the expected frequency of median-involved crashes. For example, divided highway sections with an adjacent median side-slope of 6:1 (-16.67 percent) would have a lower expected median-involved crash frequency when compared to sections that have adjacent median side-slopes of 4:1 (-25 percent). Lastly, a one unit increase in the opposing median cross-slope decreases the expected crash frequency by approximately 1 percent.

Table 9. Alternative California Median-Involved Crash Analysis Results (Traversable Sections with No Longitudinal Barrier).

Parameter	df	Estimate	Standard Error	Confidence Limits		Wald Chi-square	p-value
				Lower	Upper		
Intercept	1	-9.918	0.491	-10.725	-9.111	408.78	<0.0001
AADT (log)	1	1.020	0.045	0.947	1.094	521.69	<0.0001
Length (log)	1	0.856	0.025	0.816	0.897	1217.98	<0.0001
MW	1	-0.003	0.001	-0.005	-0.001	4.58	0.032
AdjSlope	1	-0.014	0.007	-0.026	-0.003	4.07	0.044
OppSlope	1	-0.009	0.006	-0.018	0.001	2.07	0.150
Dispersion	1	0.425	0.030	0.379	0.476		

Notes:
$\alpha = 0.10$
Number of observations: 1,107
Deviance (value/df): 1,216.046 (1.105)
Pearson chi-square (value/df): 989.015 (0.898)

North Carolina

Table 10 shows the range of explanatory variables used in the North Carolina median-involved crash analysis.

Table 10. North Carolina Median-Involved Crash Variables (Traversable Sections with No Median Barrier, 1992 – 1994).

Variable Name	Description	Variable Type	Descriptive Measures		
			Min	Max	Avg
TMEDREL	Number of median-involved crashes per year per highway section	Count (Response)	0	12	0.38
SEG_LNG	Segment length (miles)	Continuous	0.1	4.7	0.5
AADT	Average annual daily traffic (vehicles per day)	Continuous	8,900	109,300	29,070
OP_SLOP	Opposite side median slope (percent)	Continuous	-25.4	14.8	-8.1
OP_SLNG	Opposite side median slope length (feet)	Continuous	5	103	25.4
AD_PAVSHD	Adjacent side paved shoulder width (feet)	Continuous	1	21	4.7
AD_SLOP	Adjacent side median slope (percent)	Continuous	-25.4	12.9	-8.1
AD_SLGN	Adjacent side median slope length (feet)	Continuous	5	103	25.4
MEDWID	Median width (feet)	Continuous	11	217	50.7

Figure 9 is a scatter plot of median-involved crashes on traversable, divided highway sections in North Carolina. Based on the data shown in Figure 9, approximately 20.4 percent of median-involved crashes on North Carolina divided, traversable highway sections occur in the region titled “Evaluate Need for Barrier” based on existing AASHTO median barrier warrant criteria. About 33.5 percent and 46.1 percent of median-involved crashes occurred on highway sections that fall within the regions labeled “Barrier Optional” and “Barrier Not Normally Considered”, respectively, based on existing AAHSTO design criteria.

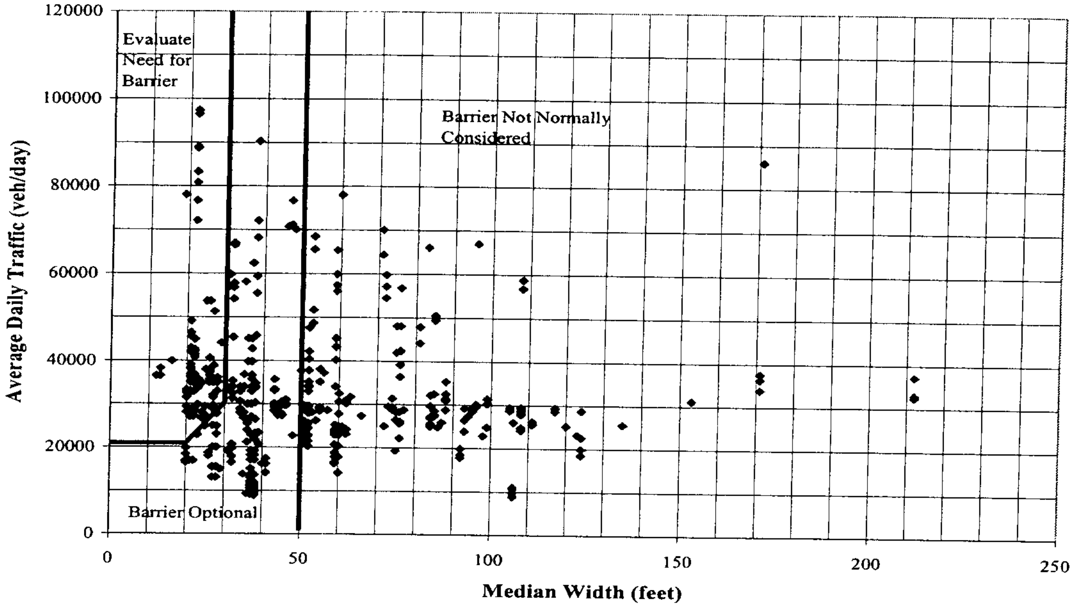

Figure 9. Scatter Plot of North Carolina Median-Involved Crashes

Predictive Modeling Results. Negative binomial regression was used to develop the median-involved crash frequency model using the general model form shown in Equation 1. All explanatory variables shown in Table 10 were included in preliminary model with interaction terms. Again, certain explanatory variables were highly correlated thus a final model with only the median width, ADT, and median cross-slopes was estimated. The final model results are shown in Table 11. Interpretation of the results shows that the median-involved crash prediction model is a better fit than the cross-median crash model for the same sections of traversable highway with no median barrier. The ADT and median width variables are statistically significant at the 10 percent level; however, the median cross-slope variables are not significant.

To understand the effect of median width and median cross-slopes on median-involved crashes, the cross-median and median-involved crash frequency models were examined jointly. Consider the influence of median width on cross-median and median-involved crash frequency on sections of highway without longitudinal barrier with traversable median cross-slopes. Let the crash frequency of the cross-median crash model be λ_{CMC}, and the crash frequency of the median-involved crash frequency model be λ_{MI}. Provided that all of the remaining explanatory variables in both models remain the same, the ratio of these crash frequencies is $\lambda_{CMC}/\lambda_{MI}$. For median width, the relative effect ratio becomes exp(-0.010)/exp(-0.004) = exp(-0.014) = 98.6 percent. This suggests that a one unit increase in the median width decreases the expected cross-median crash frequency by 1.4 percent when compared to the median-involved crash frequency. This same procedure can be used to compare the adjacent and opposite median cross-slopes.

The relative effect ratio for the adjacent slope is exp(-0.047)/exp(-0.022) = exp(-0.025) = 97.5 percent. For the opposite median cross-slope, the relative effect ratio is exp(0.028)/exp(0.015) = exp(0.013) = 101.3 percent. This indicates that a one unit increase in the adjacent median cross-slope decreases the expected cross-median crash frequency by 2.5 percent when compared to median-involved crash frequency on the same highway sections. Increasing the opposite median cross-slope by one unit results in a 1.3 percent increase in the cross-median crash frequency, when compared to the median-involved crash frequency.

Table 11. North Carolina Median-Involved Crash Prediction Results (Traversable Sections with No Median Barrier).

Parameter	**df**	**Estimate**	**Standard Error**	**Confidence Limits**		**Wald Chi-square**	**p-value**
				Lower	**Upper**		
Intercept	1	-8.846	0.794	-10.151	-7.541	124.46	<0.0001
ADT (log)	1	0.865	0.078	0.736	0.993	122.86	<0.0001
Length (log)	1	0.806	0.037	0.744	0.867	464.58	<0.0001
Medwid	1	-0.004	0.001	-0.007	-0.002	9.22	0.002
Ad_slop	1	-0.022	0.025	-0.063	0.019	0.79	0.375
Op_slop	1	0.015	0.024	-0.025	0.055	0.39	0.531
Dispersion	1	0.546	0.094	0.411	0.725		

Notes:
$\alpha = 0.10$
Number of observations: 3,065
Deviance (value/df): 2,044.42 (0.668)
Pearson chi-square (value/df): 3,504.14 (1.146)

The comparative analysis indicates that median width has a greater safety impact on cross-median crashes than on median-involved crashes. Furthermore, median cross-slopes have a greater safety benefit on cross-median crashes than on median-involved crashes. Flatter median cross-slopes reduce cross-median crashes more so than median-involved crashes.

Ohio

The data used to develop the median-involved crash prediction model for Ohio are shown in Table 12.

Table 12. Ohio Median-Involved Crash Variables
(Traversable Sections with No Median Barrier, 1997 - 1999).

Variable Name	**Description**	**Variable Type**	**Descriptive Measures**		
			Min	**Max**	**Avg**
Crashes	Number of median-involved crashes per year per mile	Count (Response)	0	73	6.4
Length	Segment length (miles)	Continuous	0.1	28.7	5.6
ADT	Average daily traffic (vehicles per day)	Continuous	5,690	156,478	40,885
AdjSlope	Adjacent side median slope (percent)	Continuous	-21.5	12.0	-8.1
AdjSlopeLength	Adjacent side median slope length (feet)	Continuous	7	78	24.5
OppSlope	Opposite side median slope (percent)	Continuous	-23.5	-0.7	-9.1
OppSlopeLength	Opposite side median slope length (feet)	Continuous	8	218	29.6
MW	Median width (feet)	Continuous	4	240	59.9

In Ohio, a scatter plot (Figure 10) of median-involved crashes is somewhat similar to that from California. Based on the data from Ohio, 2.5 percent of median-involved crashes occur in the region of the AASHTO median barrier warrant figure labeled “Evaluate Need for Barrier.” Approximately 35.3 percent and 62.2 percent of median-involved crashes occurred on highway sections that fall within the regions labeled “Barrier Optional” and “Barrier Not Normally Considered”, respectively, based on existing AAHSTO design criteria. These results are not surprising because median barrier is typically evaluated and installed for median less than 30-feet wide and with daily traffic volumes in excess of 20,000 vehicles per day.

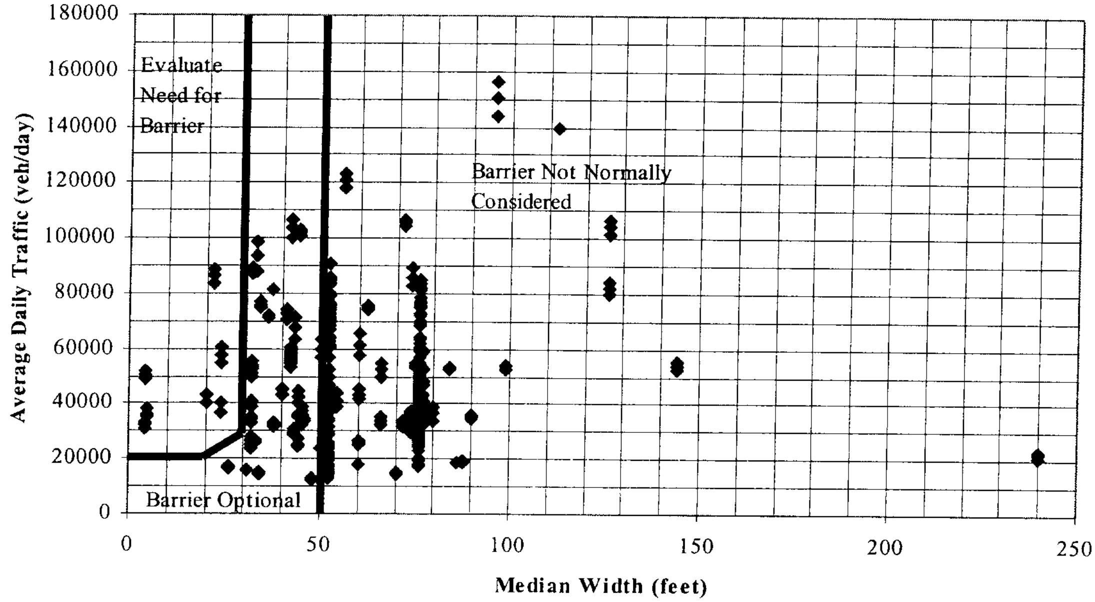

Figure 10. Scatter Plot of Ohio Median-Involved Crashes.

The distribution of Ohio median-involved crashes for those traversable roadway segments without longitudinal median barrier is shown in Figure 11. As shown, approximately 32.7 percent of the roadway segments in the Ohio data set experienced no median-involved crashes in a three-year period. More than 9 percent of the sections experienced a single median-involved crash during the three-year analysis period. About 7.6 percent of sections had two crashes during the analysis period. Such a distribution provides evidence that the negative binomial distribution should be used to model crash frequency. Exploratory analysis revealed that the general model form shown in Equation 1 is appropriate.

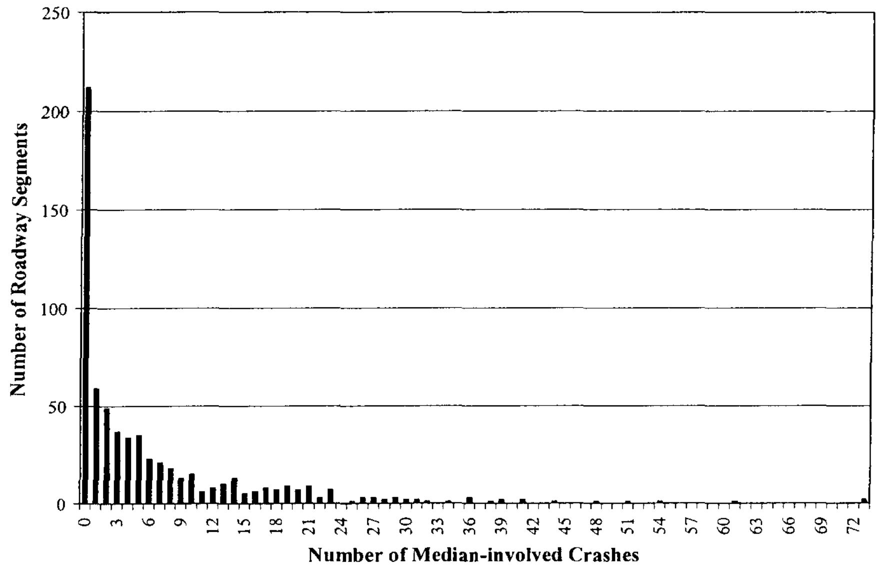

Figure 11. Ohio Median-Involved Crash Distribution (Traversable Sections with No Barrier).

Predictive Modeling Results. The same predictive modeling protocol that was used for the California and North Carolina median-involved crash analysis was used for the Ohio dataset. That is, all explanatory variables and interaction terms were included in an initial model. A second model with only the median width, ADT, and median cross-slopes was then estimated to assist with the interpretation of the results. The preliminary analysis results are shown in Table 13. The results show that traffic volume, median width, opposing median cross-slope length, and various interaction terms involving median width, median cross-slope length, and median cross-slope (percent) are all highly significant.

The Pearson chi-square statistic, divided by its degrees of freedom, equals approximately 0.95. The deviance statistic, divided by its degrees of freedom, equals approximately 1.14. The closer these values are to 1.0, the better the model fit. The relative effect of each explanatory variable, leaving all other variables constant, on the expected number of median-involved crashes can be determined by exp(parameter estimate). In order words, the relative effect of a one unit increase in median width is exp(-0.017), or a 1.7 percent reduction in the expected number of median-involved crashes per year. A one unit increase in the adjacent median cross-slope (adjslope) results in a 1.4 percent increase in the expected median-involved crash frequency on divided highways in Ohio. Similarly, a one unit increase in the opposing slope (oppslope) results in a 3.6 percent increase in the expected median-involved crash frequency. Both the adjacent and opposite median cross-slope length have a minimal effect on the expected median-involved accident frequency. All of the interaction terms also have a minimal relative effect on median-involved crash experience.

Table 13. Ohio Median-Involved Crash Analysis Results
(Traversable Sections with No Longitudinal Barrier).

Parameter	**df**	**Estimate**	**Standard Error**	**Confidence Limits**		**Wald Chi-square**	**p-value**
				Lower	**Upper**		
Intercept	1	-13.596	0.855	-15.003	-12.189	252.80	<0.0001
ADT (log)	1	1.379	0.079	1.248	1.509	301.78	<0.0001
Length (log)	1	0.746	0.037	0.685	0.806	409.76	<0.0001
MW	1	-0.017	0.008	-0.029	-0.005	5.07	0.024
AdjSlope	1	0.014	0.048	-0.064	0.092	0.09	0.763
AdjSlopeL	1	-0.003	0.010	-0.019	0.013	0.11	0.741
OppSlope	1	0.036	0.053	-0.052	0.124	0.45	0.502
OppSlopeL	1	0.016	0.010	0.001	0.032	2.73	0.098
AdjSlope*AdjSlopeL	1	-0.001	0.001	-0.002	0.001	0.14	0.709
OppSlope*OppSlopeL	1	0.002	0.001	-0.001	0.003	2.07	0.150
MW*AdjSlope	1	0.001	0.001	-0.001	0.002	0.15	0.700
MW*OppSlope	1	-0.002	0.001	-0.003	-0.001	5.05	0.025
Dispersion	1	0.661	0.062	0.567	0.771		

Notes:
$\alpha = 0.10$
Number of observations: 648
Deviance (value/df): 723.212 (1.137)
Pearson chi-square (value/df): 604.509 (0.951)

Results for the revised median-involved crash frequency model are shown in Table 14. Interpretation of the results is the same as discussed previously. Based on the results, a one unit increase in the median width (holding all other explanatory variables constant) decreases the expected cross-median crash frequency by less than one percent. A one unit increase in the adjacent median cross-slope increases the expected crash frequency by nearly 3 percent, thus suggesting that flatter depressed median cross-slopes, adjacent to the travel lanes, increases the expected frequency of median-involved crashes. For example, divided highway sections with an adjacent median side-slope of 6:1 (-16.67 percent) would have a higher expected median-involved crash frequency when compared to sections that have adjacent median side-slopes of 4:1 (-25 percent). Lastly, a one unit increase in the opposing median cross-slope decreases the expected crash frequency by approximately 4 percent.

Table 14. Final Ohio Median-Involved Crash Analysis Results
(Traversable Sections with No Longitudinal Barrier).

Parameter	**df**	**Estimate**	**Standard Error**	**Confidence Limits**		**Wald Chi-square**	**p-value**
				Lower	**Upper**		
Intercept	1	-14.049	0.818	-15.394	-12.704	295.07	<0.0001
ADT (log)	1	1.369	0.077	1.242	1.496	314.13	<0.0001
Length (log)	1	0.748	0.037	0.687	0.808	419.48	<0.0001
Medwid	1	-0.0002	0.002	-0.003	0.002	0.01	0.909
AdjSlope	1	0.027	0.013	0.005	0.049	3.97	0.046
OppSlope	1	-0.038	0.015	-0.062	-0.014	6.84	0.009
Dispersion	1	0.678	0.063	0.582	0.790		

Notes:
$\alpha = 0.10$
Number of observations: 648
Deviance (value/df): 720.53 (1.122)
Pearson chi-square (value/df): 615.792 (0.959)

Non-traversable Sections with No Longitudinal Median Barrier

Sections of divided highway that are non-traversable with no longitudinal median barrier may contain a variety of different field conditions. In most cases, however, non-traversable sections are covered with natural vegetation (i.e., trees, dense brush, etc.), thus vehicles that leave the roadway traveling in one direction cannot collide with vehicles traveling in the opposite direction. This section is divided into a discussion of the data and resulting median-involved crash frequency analysis using data from California, North Carolina, and Ohio.

California

There were 993 median-involved crashes that occurred on 157 miles of non-traversable sections with no longitudinal barrier in California between 1993 and 1995. The data used to estimate a median-involved crash prediction model are shown in Table 15.

Table 15. California Non-Traversable Median-Involved Crash Data.

Variable Name	Description	Variable Type	Descriptive Measures		
			Min	**Max**	**Avg**
Crashes	Number of median-involved crashes per year per mile	Count (Response)	0	60	4.1
Length	Segment length (miles)	Continuous	0.1	17.5	1.9
AADT	Average daily traffic (vehicles per day)	Continuous	10,625	143,706	38,591
AdjSlope	Adjacent side median slope (percent)	Continuous	-24.0	29.0	-3.0
AdjSlopeL	Adjacent side median slope length (feet)	Continuous	2	57	16.3
OppSlope	Opposite side median slope (percent)	Continuous	-24.0	29.0	-3.3
OppSlopeL	Opposite side median slope length (feet)	Continuous	7	82	37.0
Coverage	Proportion of median covered with natural barrier	Categorical	1: None 2: Less than one-third coverage 3: 1/3 to 2/3 coverage 4: Greater than 2/3 coverage		
Elevation	Difference in elevation between the profile grade lines	Categorical	1: None 2: Less than 5 feet 3: Greater than 5 feet		

Of the 157 miles of non-traversable median used in the analysis, approximately 22.2 percent have no natural barrier between the opposing travel directions. About 7 percent have natural barrier in less than one-third of the section. Approximately 14 percent of non-traversable sections contain a natural barrier covering between one-third and two-thirds of the section. The remaining sections (57 percent) contain a natural barrier for more than two-thirds of the section.

Nearly 54 percent of the roadway sections included in the analysis had no difference in elevation between the profile grade lines for opposing roadways. Approximately 26 percent and 20 percent had less than a 5-foot and greater than a 5-foot elevation difference, respectively. The non-traversable crash frequency distribution is shown in Figure 12.

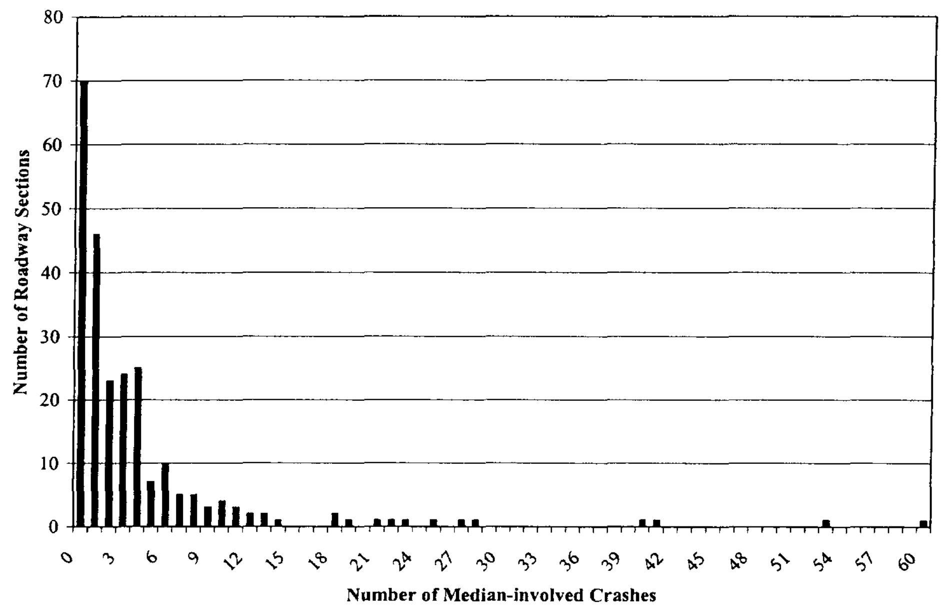

Figure 12. Median-involved Crash Distribution
(Non-Traversable Sections with No Barrier).

From Figure 12, approximately 29 percent of the roadway sections had no crash experience during the three-year analysis period. More than 19 percent of the roadway sections experienced one median-involved crash between 1993 and 1995. Negative binomial regression was used to estimate a crash prediction model – the most appropriate general model form is shown in Equation 1. The final results of the analysis are shown in Table 16.

All of the explanatory variables shown in Table 15 were included in the analysis. Based on the results, the model fit is adequate based on the deviance and Pearson chi-square statistics, divided by their respective degrees of freedom. Median width was not included in the final model because it has no influence on median-involved crashes on non-traversable sections of highway with no longitudinal median barrier.

Many of the explanatory variables are statistically significant at the 10 percent. General trends suggest that increasing the adjacent median cross-slope slightly increases the expected median-involved crash frequency; however, a one unit increase in the opposite median cross-slope slightly decreases the expected median-involved crash frequency. Similar, positive signs for the adjacent and opposite median side-slope lengths indicate that expected median-involved crash frequency increases by less than one percent for each unit increase in the slope length. No elevation difference between the profile grade of opposing roadways increases the expected median-involved crash frequency by more than 100 percent when compared to sections that that have a profile grade difference of more than 5-feet. Similarly, a profile grade difference between 0- and

5-feet increases the expected accident frequency by more than 150 percent when compared to sections that have profile grade differences greater than 5-feet. Also, increasing the amount of coverage in the median on divided highways generally increases the expected number of reported median-involved crashes. The non-traversable median-involved crash analysis does confirm that traffic volume is a critical measure of median safety.

Table 16. California Non-Traversable Median-Involved Crash Analysis Results.

Parameter	df	Estimate	Standard Error	Confidence Limits		Wald Chi-square	p-value
				Lower	Upper		
Intercept	1	-11.816	1.503	-14.289	-9.343	61.78	<0.0001
AADT (log)	1	1.132	0.139	0.903	1.361	66.27	<0.0001
Length (log)	1	0.818	0.060	0.719	0.916	187.43	<0.0001
AdjSlope	1	0.015	0.031	-0.036	0.066	0.23	0.630
OppSlope	1	-0.001	0.032	-0.054	0.052	0.00	0.976
AdjSlopeL	1	0.005	0.006	-0.005	0.015	0.68	0.408
OppSlopeL	1	0.003	0.004	-0.003	0.009	0.54	0.462
Coverage (none)	1	-0.279	0.201	-0.609	0.051	1.93	0.165
Coverage (< 1/3)	1	-0.645	0.278	-1.102	-0.188	5.40	0.020
Coverage (1/3 to 2/3)	1	-0.280	0.192	-0.596	0.037	2.11	0.146
Elevation (none)	1	0.815	0.215	0.462	1.168	14.44	0.0001
Elevation (< 5 ft)	1	1.022	0.227	0.649	1.395	20.35	<0.0001
Dispersion	1	0.275	0.058	0.194	0.390		

Notes:
$\alpha = 0.10$
Number of observations: 243
Deviance (value/df): 254.246 (1.101)
Pearson chi-square (value/df): 223.445 (0.967)

North Carolina

The dataset used for the analysis is shown in Table 17. Median-involved crash data from 1992 through 1994, inclusive, were used for the analysis. Of the 112.5 miles of non-traversable median used in the analysis, approximately 25 percent (27.7 miles) had no natural barrier between the opposing travel directions. Nearly 26 percent (28.8 miles) have natural barrier in less than one-third of the section. Approximately 32 percent (36.3 miles) of non-traversable sections contain a natural barrier covering between one-third and two-thirds of the section. The remaining sections (19.7 miles) contain a natural barrier for more than two-thirds of the section.

Table 17. Non-Traversable Median-Involved Crash and Roadway Inventory Data.

Variable Name	Description	Variable Type	Descriptive Measures		
			Min	Max	Avg
TMEDREL	Number of median-involved crashes per year per highway section	Count (Response)	0	6	0.32
SEG_LNG	Segment length (miles)	Continuous	0.1	4.0	0.4
AADT	Average annual daily traffic (vehicles per day)	Continuous	8,900	109,300	32,930
OP_SLOP	Opposite side median slope (percent)	Continuous	-19.2	9.5	-8.0
OP_SLNG	Opposite side median slope length (feet)	Continuous	5	150	32.5
AD_SLOP	Adjacent side median slope (percent)	Continuous	-19.2	9.5	-8.0
AD_SLGN	Adjacent side median slope length (feet)	Continuous	5	150	32.5
MED_COV	Proportion of median covered with natural barrier	Categorical	1: None 2: Less than one-third coverage 3: 1/3 to 2/3 coverage 4: Greater than 2/3 coverage		
Elevation	Difference in elevation between the profile grade lines	Categorical	1: None 2: Less than 5 feet 3: Greater than 5 feet		

The results of the analysis are shown in Table 18. Initial analyses indicated that the parameter estimates for the ADT and intercept was not statistically significant at the 0.20 level. This result was unexpected when compared to models previously developed using North Carolina median-involved data. As a result, an exposure variable (AADT * section length) was created and the final model results are shown in Table 18. The model adequately fits the data based on the goodness-of-fit measures. The exposure variable, median coverage, and median cross-slope lengths are all statistically significant at the 10 percent level. Interpretation of the results indicates that increased median coverage increases the median-involved crash frequency. An elevation difference of greater than 5-feet between the profile grade of opposing travel directions decreases the expected median-involved crash frequency by less than 10 percent when compared to sections that that have no profile grade difference. Similarly, a profile grade difference between 0- and 5-feet increases the expected accident frequency by nearly 15 percent when compared to sections that have no profile grade difference. Also, a low to moderate amount of median coverage (none to less than two-thirds) decreases the expected median-involved crash frequency when compared to sections with high amounts of median coverage (greater than two-thirds).

Table 18. North Carolina Non-Traversable Median-Involved Crash Analysis Results with Exposure Variable.

Parameter	**df**	**Estimate**	**Standard Error**	**Confidence Limits**		**Wald Chi-square**	**p-value**
				Lower	**Upper**		
Intercept	1	-8.380	0.785	-9.761	-7.089	113.96	<0.0001
Exposure (log)	1	0.767	0.077	0.641	0.894	99.52	<0.0001
Ad_slop	1	-0.035	0.041	-0.102	0.033	0.70	0.402
Med_cov (None)	1	-0.562	0.223	-0.930	-0.195	6.34	0.012
Med_cov (< 1/3)	1	-0.463	0.232	-0.845	-0.081	3.97	0.046
Med_cov (1/3 – 2/3)	1	-0.630	0.224	-0.998	-0.262	7.94	0.005
Op_slop	1	-0.029	0.042	-0.099	0.041	0.47	0.494
Op_slgn	1	0.014	0.006	0.003	0.024	4.72	0.030
Ad_slgn	1	-0.014	0.007	-0.026	-0.002	3.90	0.048
Elev (< 5 feet)	1	0.138	0.173	-0.146	0.422	0.64	0.423
Elev (> 5 feet)	1	-0.097	0.231	-0.477	0.283	0.18	0.673
Dispersion	1	0.598	0.199	0.347	1.033		

Notes:
$\alpha = 0.10$
Number of observations: 922
Deviance (value/df): 582.12 (0.639)
Pearson chi-square (value/df): 1,046.60 (1.149)

Ohio

There were 314 median-involved crashes that occurred on non-traversable sections with no longitudinal barrier in Ohio between 1997 and 1999. A summary of the available data for use in the analysis is shown in Table 19.

Table 19. Ohio Non-Traversable Median-Involved Crash and Roadway Inventory Data.

Variable Name	Description	Variable Type	Descriptive Measures		
			Min	Max	Avg
Crashes	Number of median-involved crashes per year per mile	Count (Response)	0	24	3.6
Length	Segment length (miles)	Continuous	0.1	14.8	2.6
ADT	Average daily traffic (vehicles per day)	Continuous	18,131	60,502	33,516
AdjSlope	Adjacent side median slope (percent)	Continuous	-26	-4.2	-8.3
AdjSlopeL	Adjacent side median slope length (feet)	Continuous	10	36	18.6
OppSlope	Opposite side median slope (percent)	Continuous	-22.3	-5	-10.5
OppSlopeL	Opposite side median slope length (feet)	Continuous	7	61	38.9
Coverage	Proportion of median covered with natural barrier	Categorical	1: None 2: Less than one-third coverage 3: 1/3 to 2/3 coverage 4: Greater than 2/3 coverage		
Elevation	Difference in elevation between the profile grade lines	Categorical	1: None 2: Less than 5 feet 3: Greater than 5 feet		

Of the 76 miles of non-traversable median used in the analysis, approximately 40 percent have no natural barrier between the opposing travel directions. Nearly 18 percent have natural barrier in less than one-third of the section. Approximately 21 percent of non-traversable sections contain a natural barrier covering between one-third and two-thirds of the section. The remaining sections (21 percent) contain a natural barrier for more than two-thirds of the section.

Nearly 51 percent of the roadway sections included in the analysis had difference in elevation between the profile grade lines for opposing roadways. Approximately 17 percent and 32 percent had less than a 5-foot and greater than a 5-foot elevation difference, respectively. The non-traversable crash frequency distribution is shown in Figure 13.

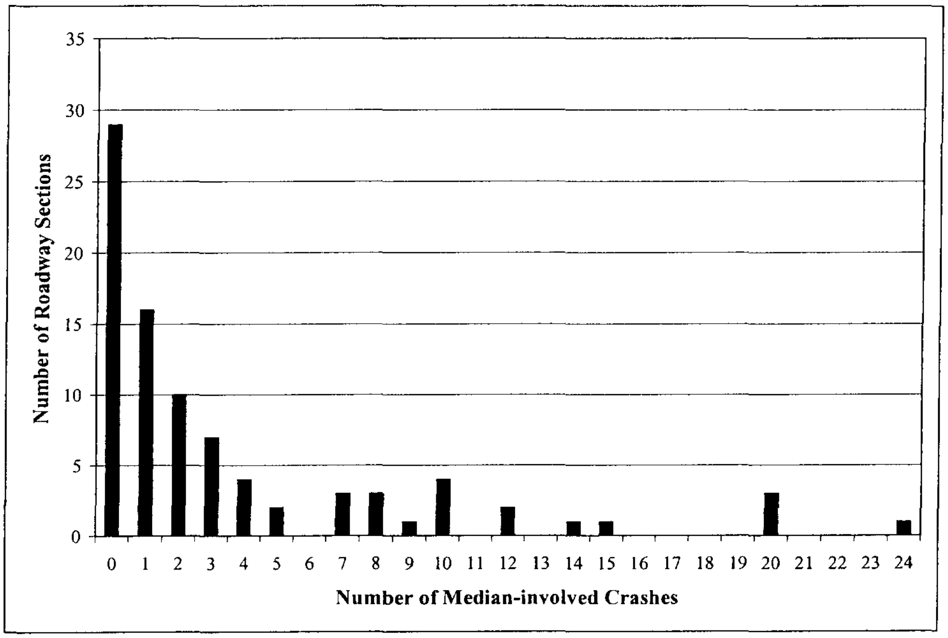

Figure 13. Ohio Median-Involved Crash Distribution
(Non-Traversable Sections with No Barrier).

From Figure 13, approximately 33 percent of the roadway sections had no crash experience during the three-year analysis period. More than 18 percent of the roadway sections experienced one median-involved crash between 1997 and 1999. Negative binomial regression was used to estimate a crash prediction model – the most appropriate general model form is shown in Equation 1. The results of the analysis are shown in Table 20.

All of the explanatory variables shown in Table 19 were included in the initial analysis. The final model results are shown in Table 5. Based on the results, the model fit is adequate based on the deviance and Pearson chi-square statistics, divided by their degrees of freedom. Hypothesis tests indicate that few of the explanatory variables are statistically significant at the 10 percent. The opposite signs for the adjacent and opposite median side-slopes and side-slopes lengths indicate that one decrease and the other increases the expected crash frequency on non-traversable sections of divided highway in Ohio. No elevation difference between the profile grade of opposing roadways decreases the expected median-involved crash frequency by 28 percent when compared to sections that that have a profile grade difference of more than 5-feet. Similarly, a profile grade difference between 0- and 5-feet decrease the expected accident frequency by 52 percent when compared to sections that have profile grade differences greater than 5-feet. The non-traversable median-involved crash analysis does confirm that traffic volume is a critical measure of median safety.

Table 20. Ohio Non-Traversable Median-Involved Crash Analysis Results.

Parameter	df	Estimate	Standard Error	Confidence Limits		Wald Chi-square	p-value
				Lower	Upper		
Intercept	1	-20.806	3.931	-27.272	-14.341	28.02	<0.0001
ADT (log)	1	2.038	0.373	1.425	2.651	29.89	<0.0001
Length (log)	1	0.969	0.104	0.800	1.141	86.32	<0.0001
AdjSlope	1	0.043	0.033	-0.011	0.098	1.71	0.191
OppSlope	1	-0.016	0.023	-0.053	0.021	0.49	0.486
AdjSlopeL	1	0.045	0.024	0.006	0.085	3.50	0.062
OppSlopeL	1	-0.016	0.007	-0.028	-0.004	5.06	0.025
Coverage (none)	1	0.185	0.265	-0.250	0.620	0.49	0.484
Coverage (< 1/3)	1	0.531	0.322	0.002	1.060	2.73	0.099
Coverage (1/3 to 2/3)	1	0.684	0.405	0.018	1.351	2.85	0.091
Elevation (none)	1	-0.332	0.316	-0.851	0.188	1.10	0.294
Elevation (< 5 ft)	1	-0.724	0.394	-1.372	-0.078	3.39	0.066
Dispersion	1	0.016	0.033	0.001	0.494		

Notes:
$\alpha = 0.10$
Number of observations: 87
Deviance (value/df): 91.463 (1.220)
Pearson chi-square (value/df): 97.258 (1.297)

Median Barrier Sections

Analysis of median-involved crashes on sections of highway with longitudinal median barrier provided insight about crash frequency with respect to barrier offset from the travel lanes, paved shoulder width, and paved shoulder slope. This section is divided into a discussion of the data and resulting median-involved crash frequency analysis using data from California, North Carolina, and Ohio.

California

The data used to estimate the crash prediction model are shown in Table 21. The adjacent median side slope variable (adjslope) is the cross-slope from the edge of the traveled way to the face of the median barrier. When the barrier is not located on a paved surface, the adjacent slope variable is the measured median cross-slope between the barrier and the paved shoulder. In many instances, it is the cross-slope of the left-side paved shoulder.

Approximately 14.4 percent (88 miles) of sections experienced no median-involved crashes during the three year period in which data were available. About 12.3 percent (75 miles) experienced one median-involved crash; and, nearly 4 percent (24 miles) of sections with longitudinal median barrier experienced more than 50 median-involved crashes.

Table 21. Median-Involved Crash and Roadway Inventory Data for Sections with Median Barrier in California.

Variable Name	Description	Variable Type	Descriptive Measures		
			Min	Max	Avg
Crashes	Number of median-involved crashes per year per mile	Count (Response)	0	209	11.2
Length	Segment length (miles)	Continuous	0.1	43.0	2.9
AADT	Average annual daily traffic (vehicles per day)	Continuous	9,500	200,426	68,105
AdjSlope	Adjacent side median slope (percent)	Continuous	-9	12	-2.0
PaveShld	Adjacent side paved shoulder width (feet)	Continuous	0	41	7.4
Offset	Distance from the edge of traveled way to median barrier (feet)	Continuous	0	52	14.6

A negative binomial distribution was used to estimate a median-involved crash frequency model for roadway sections containing longitudinal median barrier. The general model form is shown in Equation 1. The model results are shown in Table 22.

Table 22. California Median Barrier Crash and Roadway Inventory Data.

Parameter	df	Estimate	Standard Error	Confidence Limits		Wald Chi-square	p-value
				Lower	Upper		
Intercept	1	-7.836	0.558	-8.754	-6.918	197.15	<0.0001
AADT (log)	1	0.843	0.050	0.761	0.926	282.25	<0.0001
Length (log)	1	0.932	0.027	0.888	0.977	1168.64	<0.0001
PaveShld	1	-0.019	0.006	-0.029	-0.009	9.80	0.002
AdjSlope	1	-0.007	0.010	-0.024	0.009	0.52	0.471
Offset	1	0.002	0.004	-0.004	0.008	0.27	0.602
Dispersion	1	0.390	0.031	0.342	0.445		

Notes:
$\alpha = 0.10$
Number of observations: 624
Deviance (value/df): 699.329 (1.132)
Pearson chi-square (value/df): 511.952 (0.828)

Interpretation of the statistical output indicates that paved shoulder width is statistically significant and that the cross-slope between the edge of the travel and face of the median, and the offset distance from the travel lane to the barrier, are not statistically significant. The model goodness of fit is very good based on the deviance and Pearson chi-square statistics, divided by their respective degrees of freedom. General trends from the analysis indicate that a one unit increase in the lateral offset between the median barrier and edge of traveled way has virtually no effect on median-involved crash frequency. For a one unit increase in the adjacent paved shoulder width, the median-involved crash frequency decreases by nearly 2 percent. A one unit increase in the adjacent slope decreases the expected accident frequency by less than one-half percent.

North Carolina

The data used to estimate the North Carolina median barrier crash prediction model are shown in Table 23. Approximately 200 miles of data were collected at divided highway sections with median barrier. Since median-involved crashes with median barrier involve only vehicle traveling in one direction, only single direction traffic volumes were used in the analysis. Because directional distribution data were not available, one-half the traffic volume for each section calculated. The adjacent slope variable included in Table 23 is for the paved shoulder width cross slope in cases where the barrier is positioned on a paved surface. When the barrier is not located on a paved surface, the adjacent slope variable is the measured median cross-slope between the barrier and the paved shoulder. Regardless of the definition, the adjacent slope measurement was taken in close proximity to the longitudinal median barrier and reflects the field condition that vehicles encounter immediately prior to colliding with a barrier.

Table 23. North Carolina Median Barrier Crash and Roadway Inventory Data.

Variable Name	**Description**	**Variable Type**	**Descriptive Measures**		
			Min	**Max**	**Avg**
TMEDREL	Number of median-involved crashes per year per highway section	Count (Response)	0	12	0.26
SEG_LNG	Segment length (miles)	Continuous	0.1	4.7	0.5
AADT	Average annual daily traffic (vehicles per day)	Continuous	9,000	109,300	41,930
AD_SLOP	Adjacent side median slope (percent)	Continuous	-25.4	6.3	-7.7
AD_PAVSHD	Adjacent side paved shoulder width (feet)	Continuous	2	31	5.8
DIST_BAR	Distance from the edge of traveled way to median barrier (feet)	Continuous	5	68	19.7

A negative binomial distribution was again used to estimate the model. The general model form is shown in Equation 1. Exploratory analysis revealed that an exposure variable is more appropriate in the model than separately estimating traffic volume (AADT) and section length. Final model results are shown in Table 24.

Table 24. North Carolina Median-Involved Crash Analysis Results for Sections with Median Barrier.

Parameter	df	Estimate	Standard Error	Confidence Limits		Wald Chi-square	p-value
				Lower	Upper		
Intercept	1	-6.455	0.556	-7.339	-5.541	134.86	<0.0001
LogExpo	1	0.559	0.055	0.469	0.649	103.58	<0.0001
Dist_bar	1	0.001	0.008	-0.013	0.014	0.01	0.941
Ad_pavshd	1	0.011	0.018	-0.019	0.042	0.38	0.537
Ad_slop	1	-0.022	0.015	-0.046	0.003	2.13	0.144
Dispersion	1	1.742	0.304	1.308	2..321		

Notes:
$\alpha = 0.10$
Number of observations: 1,556
Deviance (value/df): 839.804 (0.542)
Pearson chi-square (value/df): 1,716.686 (1.107)

The exposure variable was highly significant ($p < 0.0001$); however, many of the explanatory variables were not statistically significant at the 10 percent level. The parameter estimates for the median barrier offset, paved shoulder width, and adjacent slope have virtually no affect on median-involved crashes. The model goodness of fit is adequate based on the deviance and Pearson chi-square statistics, divided by their respective degrees of freedom.

Ohio

Approximately 129 miles of data were collected at divided highway sections with median barrier in Ohio. The variables available for the analysis are the same as those described for California and North Carolina – descriptive measures are shown in Table 25. The median-involved crash frequency distribution is shown in Figure 14.

Table 25. Ohio Median Barrier Crash and Roadway Inventory Data.

Variable Name	Description	Variable Type	Descriptive Measures		
			Min	Max	Avg
Crashes	Number of median-involved crashes per year per mile	Count (Response)	0	47	5.3
Length	Segment length (miles)	Continuous	0.1	16.9	2.8
ADT	Average annual daily traffic (vehicles per day)	Continuous	8,056	152,625	57,517
AdjSlope	Adjacent side median slope (percent)	Continuous	-16.8	0	-3.0
ShldWid	Adjacent side paved shoulder width (feet)	Continuous	2	30	8.7
Offset	Distance from the edge of traveled way to median barrier (feet)	Continuous	0	76	10.8

Nearly 33 percent of the roadway sections included in the analysis experienced no median-involved crashes between 1997 and 1999. Approximately 12 percent of the sections contained one reportable median-involved crash during the three-year analysis period.

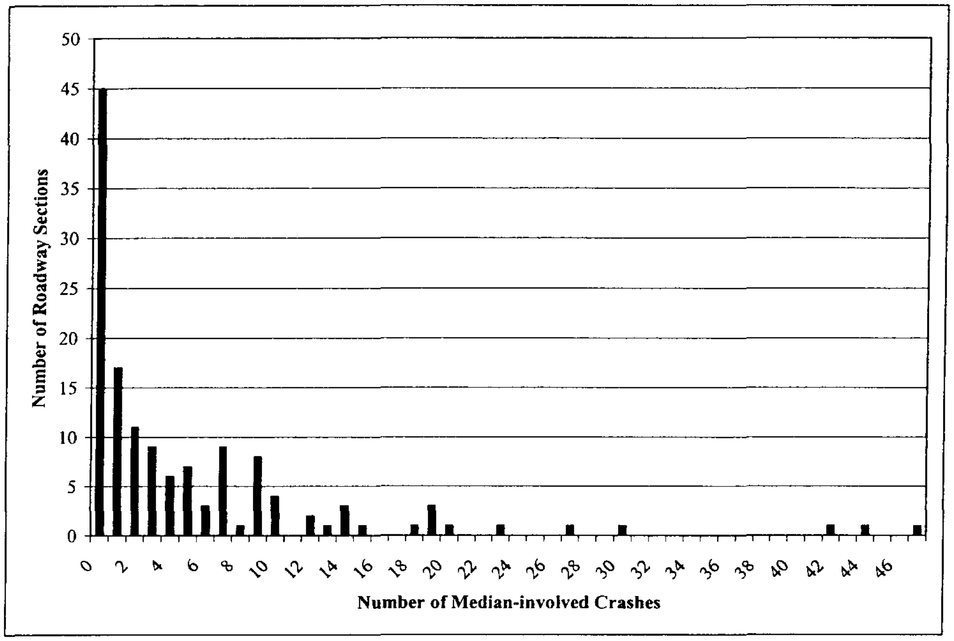

Figure 14. Ohio Median-Involved Crash Distribution for Sections with Median Barrier.

A negative binomial distribution was used to estimate a median-involved crash frequency model for roadway sections containing longitudinal median barrier in Ohio. The general model form is shown in Equation 1. The model results, including all of the predictor variables, are shown in Table 26.

Table 26. Ohio Median-Involved Crash Analysis Results for Sections with Median Barrier.

Parameter	**df**	**Estimate**	**Standard Error**	**Confidence Limits**		**Wald Chi-square**	**p-value**
				Lower	**Upper**		
Intercept	1	-4.086	1.521	-6.587	-1.584	7.22	0.007
ADT (log)	1	0.459	0.150	0.213	0.705	9.42	0.002
Length (log)	1	0.903	0.091	0.753	1.052	98.76	<0.0001
ShldWid	1	0.029	0.016	0.003	0.055	3.25	0.071
AdjSlope	1	-0.007	0.019	-0.037	0.024	0.13	0.719
Offset	1	-0.008	0.007	-0.020	0.003	1.38	0.241
Dispersion	1	0.573	0.155	0.411	0.797		

Notes:
$\alpha = 0.10$
Number of observations: 136
Deviance (value/df): 143.967 (1.107)
Pearson chi-square (value/df): 123.026 (0.946)

The model goodness of fit is very good based on the deviance and Pearson chi-square statistics, divided by their respective degrees of freedom. General trends from the analysis indicate that a one unit increase in the lateral offset between the median barrier and edge of traveled way decreases median-involved crash frequency by less than one percent. An opposite trend occurs for the adjacent paved shoulder width variable where a one unit increases in the width increase the expected median-involved crash frequency by nearly three percent. A one unit increase in the adjacent slope decreases the expected accident frequency by less than one percent.

BEFORE-AFTER ANALYSIS OF SLOPE FLATTENING PROJECTS IN IOWA

Hauer (*15*) has developed an Empirical Bayes' (EB) procedure that safety researchers can use to estimate the safety effects of treatments using observed before and after crash counts. Recent studies (16, *17*) have successfully used the method to estimate the before-after effects of safety treatments of turn-lanes and roundabout conversions. The appropriateness of the procedure lies in its ability to correct for regression-to-the-mean bias and to increase the precision of safety estimates. This section describes how the EB procedure was used to estimate the safety effects of median slope-flattening on Iowa Interstate highways. A reference group, consisting of Iowa Interstate highways that were not treated with median slope-flattening was chosen based on similarities to the treated sites. A negative binomial regression model was estimated for the reference group. This model was then combined with observed accident counts at the treated sites in the before period to estimate the median-involved accident frequency in the after period had the sites not been improved.

Description of Data

Two datasets were used for the EB analysis: (1) reference group data from 1987 through 1996, and (2) treatment group data. The reference group consisted of all divided, interstate highways that did not contain longitudinal median barrier. Also, the reference group only consisted of medians that were up to 100 feet wide. Approximately 600 miles of Interstate highway were part of the reference group. The treatment group consisted of 157 miles (18 locations) where median side slopes were flattened from 4:1 to 6:1. The re-grading effort took place in 1992 and 1993. Three years of before-after crash data are available for each treated location. Table 27 provides detailed information about the reference group data utilized for the analysis.

Table 27. Iowa Reference Group Data.

Variable Name	Description	Variable Type	Range of Values		
			Min.	Max.	Avg.
TotalCrash	Total number of median-involved crashes per section	Response (Count)	0	5	0.08
Length	Section length (miles)	Predictor	0.01	2.9	0.3
AADT	Average annual daily traffic (vehicles/day)	Predictor	1,860	97,600	17,494
MedianWidth	Median width (feet)	Predictor	2	100	53.9

The data shown in Table 27 were developed by appending electronic crash records to electronic roadway inventory data. A new section in the electronic roadway inventory data was created when either geometric, cross-section, or traffic characteristics changed on adjacent sections. This resulted in the reference group dataset having homogeneous sections; however, nearly one-third of the sections had lengths of less than one-quarter mile. To overcome this limitation, the data were aggregated to create longer homogeneous sections of divided Interstate highway. The aggregation procedure was based on roadway sections having the same county and route, and similar median widths (i.e., less than 5 percent difference between adjacent sections). Also, average annual daily traffic (AADT) volumes were considered in the aggregation process. A weighted average of AADT for each aggregated section was calculated based on subsection lengths. Descriptive measures of the aggregated data are shown in Table 28.

Table 28. Aggregated Iowa Reference Group Data.

Variable Name	Description	Variable Type	Range of Values		
			Min.	Max.	Avg.
TotalCrash	Total number of median-involved crashes per section	Response (Count)	0	17	3.2
Length	Section length (miles)	Predictor	0.2	34.5	10.0
AADT	Average annual daily traffic (vehicles/day)	Predictor	3,406	85,325	19,210
MedianWidth	Median width (feet)	Predictor	3	91	51.1

By aggregating the reference group data, the average section length increased from 0.3 miles to 10.0 miles. Further, the number of median-involved crashes per section increased from 0.08 to 3.2. Only minor differences in the AADT and median width are shown.

Analysis Results

A simple, descriptive safety comparison between the treatment sites and reference group is shown in Table 29. Although the treated sites were re-graded at different time periods, there were three years of before and three years of after crash data available for each site. When comparing the treated sections before-after crash experience, crash frequency increased at 10 sites, decreased at six sites, and remained the same at two sites. The reference group shows a decrease in crash experience.

Table 29. Median-Involved Crash Experience for Iowa Slope Flattening Sites.

Site	Rural/ Urban	Median Width	Rte.	Length of Treated Section (miles)	3-Year Before Period Frequency of Median-Involved Crashes	3-Year After Period Frequency of Median-Involved Crashes	Percent Change
1	Rural	50 ft	I-29	3.10	1	2	+100.0%
2	Rural	52 ft	I-29	5.34	2	2	0.0%
3	Rural	36 ft	I-35	6.96	3	5	+66.7%
4	Rural	36 ft	I-35	5.83	5	0	-100.0%
5	Rural & Urban	50 ft	I-35	19.08	27	25	-7.4%
6	Rural	50 ft	I-35	6.05	8	10	+20.0%
7	Rural	50 ft	I-35	4.02	4	4	0.0%
8	Urban	50 ft	I-74	4.23	3	1	-66.7%
9	Rural	50 ft	I-80	20.61	8	21	+163.5%
10	Rural	50ft	I-80	9.33	9	14	+55.6%
11	Rural	50 ft	I-80	4.80	9	5	-44.4%
12	Rural	50 ft	I-80	16.78	17	10	-41.2%
13	Rural	50 ft	I-80	13.50	12	13	+8.3%
14	Rural	50 ft	I-80	9.76	9	8	-11.1%
15	Rural	50 ft	I-80	7.90	14	16	+14.3%
16	Rural	50 ft	I-80	12.71	18	16	-11.1%
17	Rural	50 ft	I-80	3.61	5	13	+160.0%
18	Urban	50 ft	I-80	3.74	3	4	+33.3%
Total				157.35	157	169	+7.64%
Reference Group				598 miles in Before vs. 586 miles in After	638* (0.36 crashes/mi/yr)	538** 0.31 crashes/mi/yr)	-16% (-14%)

* - The before period for the reference group pertains to 1989, 1990, and 1991, inclusive.

** - The after period for the reference group pertains to 1994, 1995, and 1996.

While the results in Table 29 provide some descriptive measures of median-involved crash experience for Iowa slope-flattening projects, the EB procedure is a better safety estimation tool. Using the data shown in Table 27 and 28, a negative binomial regression model was estimated using the general model form shown in Equation 1.

The results of the modeling effort are shown in Tables 30 and 31, respectively. The model parameters for the non-aggregated data are shown in Table 30 while the model results for the aggregated dataset are shown in Table 3.

Table 30. Negative Binomial Regression Results for Non-Aggregated Data.

Parameter	df	Parameter Estimate	Standard Error	90 percent Wald Confidence Limits		Wald Chi-square	p-value
				Lower	Upper		
Intercept	1	-8.045	0.548	-8.948	-7.145	215.62	<0.0001
AADT (log)	1	0.752	0.050	0.669	0.834	224.46	<0.0001
Length (log)	1	0.840	0.027	0.795	0.885	952.50	<0.0001
MedianWidth	1	-0.009	0.003	-0.013	-0.005	11.70	0.001
Dispersion Parameter	1	0.778	0.138	0.581	1.042		
Number of Observations = 19,498 Deviance = 6039.116 Deviance/df = 0.310 Pearson chi-square = 20,118.288 Pearson chi-square/df = 1.032							

The results of the modeling effort indicate that the negative binomial distribution provides an adequate fit to the data based on the Pearson chi-square statistic, divided by its degrees of freedom. However, the Deviance statistic, divided by its degrees of freedom, indicates a relatively poor fit to the data. All of the predictor variables are highly significant. A one unit increase in the median width has a minimal effect on median-involved crash frequency.

Table 31. Negative Binomial Regression Results for Aggregated Data.

Parameter	df	Parameter Estimate	Standard Error	90 percent Wald Confidence Limits		Wald Chi-square	p-value
				Lower	Upper		
Intercept	1	-7.283	0.922	-8.798	-5.767	62.46	<0.0001
AADT (log)	1	0.739	0.083	0.603	0.876	79.38	<0.0001
Length (log)	1	0.814	0.053	0.726	0.901	234.35	<0.0001
MedianWidth	1	-0.010	0.004	-0.016	-0.004	6.76	0.010
Dispersion Parameter	1	0.274	0.051	0.202	0.372		

Number of Observations = 413
Deviance = 470.545
Deviance/df = 1.151
Pearson chi-square = 451.409
Pearson chi-square/df = 1.104

Aggregating the reference group data indicates that the negative binomial distribution provides an adequate fit to the data based on the Pearson chi-square and Deviance statistics, both divided by their degrees of freedom. All of the predictor variables are highly significant. A one unit increase in the median width again has a minimal effect on median-involved crash frequency.

The change in safety at a slope-flattened site is the difference in the expected number of crashes that would have occurred had the treatment not been implemented and the number of reported crashes in the after period. The expected number of crashes that would have occurred in the after period had the treatment not been implemented was essentially estimated by developing the regression models above. The procedure used to determine the safety effects of slope-flattening projects in Iowa is as follows:

Estimate the total number of median-involved crashes per year in the before period.

This was accomplished by substituting the treatment site characteristics (AADT, section length, and median width) into Equation 3 shown below. Since the AADT changes over the length of each treated section, a weighted estimate was entered into the regression equation to estimate the median-involved crash frequency in the before period. The median width rarely changed over the length of a treated section, thus the median width shown in Table 31 was input into the regression model.

Equation 3

$$N = \exp(-7.283) \bullet L^{0.814} \bullet ADT^{0.739} \bullet \exp(-0.010MW)$$

The expected annual number of median-involved crashes can then be estimated as a function of the before period crash counts, the duration of the before period, and a regression parameter estimate, k. Equation 4 is the expected annual number of crashes during the before period.

Equation 4

$$n_b = \frac{(k + t_b)}{((k / N) + y_b)}$$

where: k = regression parameter;

t_b = total number of observed median-involved crashes in the before period;

y_b = number of years in the before period;

N = estimated number of median-involved crashes during the before period from the regression model;

Estimate the total number of median-involved crashes per year in the after period.

This is accomplished by determining the total number of median-involved crashes per year using the regression model. Again, a weighted average for the AADT was input into the model as was the median width and section length using Equation 3. The ratio of the after and before period regression estimates is simply N_A/N_B, where N_A is the number of median-involved crashes in the after period and N_B is the number of median-involved crashes in the before period. Both of these estimates are from Equation 3 – the subscript was added to simplify the notation. Lastly, to estimate the expected number of median-involved crashes per year in the after period, the regression ratio and the expected annual number of median-involved crashes during the after period must be considered as follows:

Equation 5

$$n_a = \left(\frac{N_A}{N_B}\right) \times n_b$$

where: n_a, n_b = expected annual number of median-involved crashes during the before and after periods, respectively.

N_A, N_B = regression estimate of the median-involved crashes per year during the before and after periods, respectively.

Estimate the number of median-involved crashes that would have occurred in the after period had the median side-slopes not been flattened.

The estimate from Equation 5 is multiplied by the length of the after period (years) to obtain an estimate of the median-involved crashes that would have occurred in had median side-slope not been flattened.

Estimate Index of Effectiveness

The last step in the analysis is to determine the effectiveness of the treatment. An unbiased estimate of the index of effectiveness is given by:

Equation 6

$$\theta = \frac{(\lambda / \pi)}{\{1 + [Var(\pi) / \pi^2]\}}$$

where: θ = index of effectiveness;

λ = expected number of median-involved crashes that would have occurred in the after period without median slope-flattening;

π = number of reported crashes in the after period.

The variance of the index of effectiveness was also estimated and reported.

CHAPTER III

INTERPRETATION, APPRAISAL, AND APPLICATIONS

MEDIAN-INVOLVED CRASH ANALYSIS

This section of the report is subdivided into a discussion of median-involved crash analysis for divided, traversable highway sections with no longitudinal median barrier, for divided highway sections that are non-traversable, and for sections that contain median barrier.

Traversable Sections with No Longitudinal Median Barrier

This section is divided into a discussion of the data and resulting median-involved crash frequency analysis using data from California, North Carolina, and Ohio.

California

Based on the descriptive median safety measures and the predictive modeling efforts, it is clear that median width and traffic volumes affect the frequency of median-involved crashes in California. Further, there is also statistical evidence that median cross-slopes influence the frequency of cross-median crashes. Like the North Carolina cross-median crash analysis results presented previously, another model with a categorical variable for median cross-slope was estimated to assist with interpretation of the results. The adjacent median cross-slope was dichotomized into categories of 6:1 or steeper and flatter than 6:1. Equation 7 is the resulting model output – the model fit and parameter estimates were very similar to those presented in Table 8 in the previous chapter.

Equation 7

$$N_{CAMI} = e^{-9.299} \bullet ADT^{0.999} \bullet L^{0.859} \bullet \exp(-0.002MW) \bullet \exp(-0.338AS)$$

where: N_{CAMI} = frequency of California median-involved crashes per mile per year;

ADT = average daily traffic (vehicles per day);

L = section length (miles);

MW = median width (feet);

AS = adjacent median cross-slope (1 if flatter than 6:1; 0 otherwise).

Tables 32 and 33 show the expected cross-median crash frequency based on Equation 7.

Table 32. Expected Median-Involved Crash Frequency in California (Median Cross-Slopes Flatter than 6:1).

ADT (vpd)	Median Width (feet)										
	0	10	20	30	40	50	60	70	80	90	100
10000	0.3440	0.3372	0.3305	0.3239	0.3175	0.3112	0.3051	0.2990	0.2931	0.2873	0.2816
20000	0.6875	0.6739	0.6605	0.6474	0.6346	0.6221	0.6097	0.5977	0.5858	0.5742	0.5629
30000	1.0308	1.0104	0.9904	0.9708	0.9516	0.9327	0.9142	0.8961	0.8784	0.8610	0.8440
40000	1.3740	1.3468	1.3201	1.2940	1.2684	1.2433	1.2186	1.1945	1.1709	1.1477	1.1249
50000	1.7171	1.6831	1.6498	1.6171	1.5851	1.5537	1.5230	1.4928	1.4632	1.4343	1.4059
60000	2.0602	2.0194	1.9794	1.9402	1.9018	1.8641	1.8272	1.7910	1.7556	1.7208	1.6867
70000	2.4032	2.3556	2.3090	2.2632	2.2184	2.1745	2.1314	2.0892	2.0479	2.0073	1.9676
80000	2.7461	2.6918	2.6385	2.5862	2.5350	2.4848	2.4356	2.3874	2.3401	2.2938	2.2483
90000	3.0890	3.0279	2.9679	2.9091	2.8515	2.7951	2.7397	2.6855	2.6323	2.5802	2.5291
100000	3.4319	3.3639	3.2973	3.2320	3.1680	3.1053	3.0438	2.9835	2.9245	2.8666	2.8098

Based on the existing guidelines, the minimum expected number of median-involved crashes per mile per year is 0.6605 for the combination of ADT and median width of 20,000 vehicles per day and 20-feet wide, respectively. Using the expected cross-median crash frequency as the sole measure of median safety, this would indicate that all expected frequencies greater than 0.6605 in Table 11 be included in the "Evaluate Need for Barrier" region of revised median barrier warrant criteria. A similar interpretation of the expected cross-median crash frequency can be conducted using the data presented in Table 33.

Table 33. Expected Median-Involved Crash Frequency in California (Median Cross-Slopes 6:1 or Steeper).

ADT (vpd)	Median Width (feet)										
	0	10	20	30	40	50	60	70	80	90	100
10000	0.4829	0.4734	0.4640	0.4548	0.4458	0.4370	0.4283	0.4198	0.4115	0.4034	0.3954
20000	0.9652	0.9461	0.9274	0.9090	0.8910	0.8734	0.8561	0.8391	0.8225	0.8062	0.7902
30000	1.4472	1.4186	1.3905	1.3629	1.3360	1.3095	1.2836	1.2582	1.2332	1.2088	1.1849
40000	1.9291	1.8909	1.8534	1.8167	1.7808	1.7455	1.7109	1.6771	1.6438	1.6113	1.5794
50000	2.4108	2.3631	2.3163	2.2704	2.2254	2.1814	2.1382	2.0958	2.0543	2.0137	1.9738
60000	2.8924	2.8352	2.7790	2.7240	2.6701	2.6172	2.5654	2.5146	2.4648	2.4160	2.3681
70000	3.3740	3.3072	3.2417	3.1775	3.1146	3.0529	2.9925	2.9332	2.8751	2.8182	2.7624
80000	3.8555	3.7791	3.7043	3.6309	3.5590	3.4886	3.4195	3.3518	3.2854	3.2204	3.1566
90000	4.3369	4.2510	4.1668	4.0843	4.0035	3.9242	3.8465	3.7703	3.6957	3.6225	3.5507
100000	4.8183	4.7229	4.6293	4.5377	4.4478	4.3597	4.2734	4.1888	4.1058	4.0245	3.9449

Using the expected cross-median crash frequency as the sole measure of median safety, this would indicate that all expected frequencies greater than 0.9274 in Table 12 be included in the "Evaluate Need for Barrier" region of revised median barrier warrant criteria. When comparing the results of Tables 11 and 12, there is support for dichotomizing the median cross-slope. The expected cross-median crash frequency varies by approximately 40 percent when comparing the tables.

North Carolina

Based on the descriptive median safety measures and the predictive modeling efforts, it is clear that median width and traffic volumes affect the frequency of median-involved crashes in North Carolina. Further, there is little statistical evidence to suggest that median cross-slopes influence the frequency of median-involved crashes. Table 34 shows the expected median-involved crash frequency based on the parameter estimates shown in Table 33.

Table 34. Expected Median-Involved Crash Frequency in North Carolina.

ADT (vpd)	Median Width (feet)										
	0	10	20	30	40	50	60	70	80	90	100
10000	0.4152	0.3989	0.3833	0.3682	0.3538	0.3399	0.3266	0.3138	0.3015	0.2897	0.2783
20000	0.7562	0.7265	0.6980	0.6707	0.6444	0.6191	0.5948	0.5715	0.5491	0.5276	0.5069
30000	1.0738	1.0317	0.9913	0.9524	0.9151	0.8792	0.8447	0.8116	0.7798	0.7492	0.7198
40000	1.3773	1.3232	1.2714	1.2215	1.1736	1.1276	1.0834	1.0409	1.0001	0.9609	0.9232
50000	1.6705	1.6050	1.5420	1.4816	1.4235	1.3677	1.3140	1.2625	1.2130	1.1655	1.1198
60000	1.9558	1.8791	1.8055	1.7347	1.6667	1.6013	1.5385	1.4782	1.4202	1.3645	1.3110
70000	2.2348	2.1472	2.0630	1.9821	1.9044	1.8297	1.7580	1.6890	1.6228	1.5592	1.4980
80000	2.5084	2.4101	2.3156	2.2248	2.1376	2.0537	1.9732	1.8958	1.8215	1.7501	1.6815
90000	2.7775	2.6686	2.5639	2.4634	2.3668	2.2740	2.1848	2.0992	2.0169	1.9378	1.8618
100000	3.0425	2.9232	2.8086	2.6985	2.5927	2.4910	2.3933	2.2995	2.2093	2.1227	2.0395

Based on the existing guidelines, the minimum expected number of median-involved crashes per mile per year is 0.6980 for the combination of ADT and median width of 20,000 vehicles per day and 20-feet wide, respectively. Using the expected cross-median crash frequency as the sole measure of median safety, this would indicate that all expected frequencies greater than 0.6980 in Table 34 be included in the "Evaluate Need for Barrier" region of revised median barrier warrant criteria.

Ohio

Based on the descriptive median safety measures and the predictive modeling efforts, it is clear that traffic volumes affect the frequency of median-involved crashes in Ohio. There is also evidence that the median cross-slopes affect the frequency of median-involved crashes on traversable highway sections. Median width, however, has little influence on median-involved crash frequency. To assist with interpretation of the predictive modeling effort, another model with a categorical variable for median cross-slope was estimated to assist with interpretation of the results. The adjacent median cross-slope was dichotomized into categories of 6:1 or steeper and flatter than 6:1. Equation 8 is the resulting model output – the model fit and parameter estimates were very similar to those presented in Table 14 in the previous chapter.

Equation 8

$$N_{OHMI} = e^{-13.903} \bullet ADT^{1.387} \bullet L^{0.761} \bullet \exp(0.001MW) \bullet \exp(-0.278AS)$$

where: N_{OHMI} = frequency of Ohio median-involved crashes per mile per year;

ADT = average daily traffic (vehicles per day);

L = section length (miles);

MW = median width (feet);

AS = adjacent median cross-slope (1 if flatter than 6:1; 0 otherwise).

Tables 35 and 36 show the expected cross-median crash frequency based on Equation 8.

Table 35. Expected Median-Involved Crash Frequency in Ohio
(Median Cross-Slopes Flatter Than 6:1).

ADT (vpd)	Median Width (feet)										
	0	10	20	30	40	50	60	70	80	90	100
10000	0.2451	0.2473	0.2495	0.2518	0.2541	0.2564	0.2587	0.2610	0.2634	0.2658	0.2682
20000	0.6410	0.6468	0.6526	0.6585	0.6645	0.6705	0.6765	0.6827	0.6888	0.6951	0.7013
30000	1.1248	1.1350	1.1452	1.1556	1.1660	1.1766	1.1872	1.1980	1.2088	1.2197	1.2307
40000	1.6764	1.6915	1.7068	1.7223	1.7378	1.7535	1.7694	1.7854	1.8015	1.8178	1.8342
50000	2.2845	2.3051	2.3260	2.3470	2.3682	2.3896	2.4112	2.4330	2.4550	2.4772	2.4996
60000	2.9418	2.9684	2.9952	3.0223	3.0496	3.0772	3.1050	3.1331	3.1614	3.1900	3.2188
70000	3.6430	3.6760	3.7092	3.7427	3.7766	3.8107	3.8452	3.8799	3.9150	3.9504	3.9861
80000	4.3843	4.4239	4.4639	4.5043	4.5450	4.5861	4.6275	4.6694	4.7116	4.7542	4.7972
90000	5.1624	5.2090	5.2561	5.3036	5.3516	5.4000	5.4488	5.4980	5.5478	5.5979	5.6485
100000	5.9747	6.0287	6.0832	6.1382	6.1937	6.2497	6.3062	6.3632	6.4207	6.4788	6.5373

Based on existing AASHTO guidelines, the minimum expected number of median-involved crashes per mile per year is 0.6410 for the combination of ADT and median width of 20,000 vehicles per day and 0-feet wide, respectively. Using the expected cross-median crash frequency as the sole measure of median safety, this would indicate that all expected frequencies greater than 0.6410 in Table 35 be included in the "Evaluate Need for Barrier" region of revised median barrier warrant criteria. A similar interpretation of the expected cross-median crash frequency can be conducted using the data presented in Table 36.

Table 36. Expected Median-Involved Crash Frequency in Ohio (Median Cross-Slopes 6:1 or Steeper).

ADT (vpd)	Median Width (feet)										
	0	10	20	30	40	50	60	70	80	90	100
10000	0.3236	0.3265	0.3295	0.3325	0.3355	0.3385	0.3416	0.3446	0.3478	0.3509	0.3541
20000	0.8463	0.8540	0.8617	0.8695	0.8773	0.8853	0.8933	0.9013	0.9095	0.9177	0.9260
30000	1.4852	1.4986	1.5121	1.5258	1.5396	1.5535	1.5676	1.5817	1.5960	1.6105	1.6250
40000	2.2134	2.2334	2.2536	2.2740	2.2945	2.3153	2.3362	2.3573	2.3786	2.4002	2.4219
50000	3.0163	3.0436	3.0711	3.0989	3.1269	3.1551	3.1837	3.2124	3.2415	3.2708	3.3004
60000	3.8842	3.9193	3.9547	3.9905	4.0266	4.0630	4.0997	4.1368	4.1742	4.2119	4.2500
70000	4.8101	4.8536	4.8975	4.9417	4.9864	5.0315	5.0770	5.1229	5.1692	5.2159	5.2631
80000	5.7888	5.8411	5.8940	5.9472	6.0010	6.0553	6.1100	6.1652	6.2210	6.2772	6.3340
90000	6.8161	6.8778	6.9399	7.0027	7.0660	7.1299	7.1943	7.2594	7.3250	7.3912	7.4580
100000	7.8887	7.9600	8.0320	8.1046	8.1778	8.2518	8.3264	8.4016	8.4776	8.5542	8.6316

Using the expected cross-median crash frequency as the sole measure of median safety, this would indicate that all expected frequencies greater than 0.8463 in Table 36 be included in the "Evaluate Need for Barrier" region of revised median barrier warrant criteria. When comparing the results of Tables 35 and 36, there is support for dichotomizing the median cross-slope. The expected cross-median crash frequency varies by approximately 30 percent when comparing the tables.

Non-traversable Sections with No Longitudinal Median Barrier

Sections of divided highway that are non-traversable with no longitudinal median barrier may contain a variety of different field conditions. In most cases, however, non-traversable sections are covered with natural vegetation (i.e., trees, dense brush, etc.), thus vehicles that leave the roadway traveling in one direction cannot collide with vehicles traveling in the opposite direction.

Interpretation of the non-traversable median-involved crash frequency analysis suggests general median design trends. For instance, all analyses presented previously indicate that daily traffic volumes do influence the frequency of median-involved crashes on non-traversable sections of divided highway. There is also evidence that high amounts of median coverage increases the median-involved crash frequency. Lastly, there is some evidence that an elevation difference between the profile grade lines of opposing travel directions decreases the expected median-involved crash frequency. This finding appears to lend support for design of asymmetric medians to help reduce the frequency of median-involved crashes.

Median Barrier Sections

Analysis of median-involved crashes on sections of highway with longitudinal median barrier provided insight about crash frequency with respect to barrier offset from the travel lanes, paved shoulder width, and paved shoulder slope.

Based on the modeling results, there is little evidence the median barrier offset distance, inside paved shoulder widths, and median cross-slopes between the traveled way and longitudinal barrier significant affect median-involved crash frequency. The parameter estimates for each statewide model are relatively small in magnitude (less than $\pm$ 0.03) and, when comparing between states, are different in direction. Directional traffic volumes are the most likely variable to influence the frequency of median-involved crashes along roadway sections with longitudinal median barrier. Table 37 provides an estimate of the number of median-involved crashes that are expected per mile per year on sections of roadway with median barrier in California, North Carolina, and Ohio.

Table 37. Expected Median-Involved Crash Frequency for Roadway Sections with Median Barrier.

Directional ADT	Median-involved Crashes per Year per Mile		
	California	North Carolina	Ohio
5000	0.4946	0.2089	0.9679
10000	0.8872	0.3078	1.3305
15000	1.2487	0.3861	1.6026
20000	1.5914	0.4534	1.8289
25000	1.9208	0.5136	2.0261
30000	2.2399	0.5688	2.2030
35000	2.5508	0.6199	2.3645
40000	2.8547	0.6680	2.5140
45000	3.1527	0.7135	2.6536
50000	3.4455	0.7567	2.7851

The information contained in Table 37 was estimated based on median barrier being located immediately adjacent to the left-edge of the traveled way. There would be only a small change in values presented were the barrier to be located further from the edge of the travel lanes.

BEFORE-AFTER ANALYSIS OF SLOPE FLATTENING PROJECTS IN IOWA

Table 38 shows the results of the EB analysis for median slope flattening projects on Iowa Interstate highways. As shown, there are five sites that experienced an increase in median-involved crash frequency after flattening the median cross-slopes; however, 12 sites had a lower median-involved crash frequency in the after period. One treated site did not change from the before to the after period.

Table 38. Empirical Bayes Median-Involved Crashes at Iowa Treatment Sites.

Site	Treatment Effect of Slope Flattening			Index of Effectiveness	Standard Deviation of Effectiveness Index	Percent Accident Reduction
	Observed Before Period Crash Count	Expected After Period Accidents in Absence of Treatment	Observed After Period Count			
1	2	1.07	2	1.06	0.78	(6)
2	4	2.12	2	0.63	0.24	37
3	4	9.94	7	0.52	0.07	48
4	6	14.60	10	0.60	0.08	40
5	51	48.84	33	0.69	0.02	31
6	13	12.17	7	0.55	0.06	45
7	5	7.14	11	1.33	0.44	(33)
8	8	4.62	2	0.37	0.08	63
9	8	19.84	23	1.00	0.12	0
10	10	35.05	28	0.77	0.07	23
11	13	7.40	6	0.75	0.13	25
12	19	29.93	16	0.52	0.03	48
13	17	24.64	25	0.93	0.07	7
14	17	10.37	11	0.93	0.11	7
15	14	33.74	27	0.79	0.06	21
16	27	32.52	14	0.43	0.02	57
17	9	4.78	12	2.20	0.82	(120)
18	6	1.92	4	1.50	0.78	(50)

To further assist with interpreting the results, Table 39 shows the before and after data that were available for the EB analysis. Based on the results in Table 38, the sites that experienced an effective increase in median-involved crashes were the four shortest in length when compared to the sites the experienced an effective decrease in median-involved crashes. Although not shown in Table 38, the overall crash experience for Iowa slope-flattening projects decreased by 12 percent. This was determined using the same EB procedure outlined previously only using a weighted average of the AADT in both the before and after periods for all sections combined. The expected after period median-involved crash count in the absence of median side slope-flattening was estimated to be 273. The observed accident median-involved accident count in the after period was 240.

Table 39. Before-After Duration for Iowa Slope Flattening Sites.

Site	Years		Site	Years		Site	Years	
	Before	After		Before	After		Before	After
1	5	2	7	4	5	13	4	5
2	5	2	8	5	4	14	6	3
3	3	6	9	2	4	15	3	6
4	3	6	10	2	6	16	4	4
5	5	4	11	6	3	17	6	3
6	5	4	12	3	4	18	7	2

CHAPTER IV

CONCLUSIONS AND SUGGESTED RESEARCH

Based on the statistical modeling of cross-median crashes using data from North Carolina, it is clear that traffic volumes, median width and median side slopes all affect their frequency. Increasing the width of the median on a divided, limited-access highway decreases the expected cross-median crash frequency. Similarly, flattening the median side-slope adjacent to the traveled way reduces the frequency of cross-median crashes. Based on the data, approximately one-third of all cross-median crashes in North Carolina occur in each region of the existing AASHTO median barrier warrant criteria. These regions are designated “Evaluate Need for Barrier,” “Barrier Optional,” and “Barrier Not Normally Considered” as shown in Figure 15.

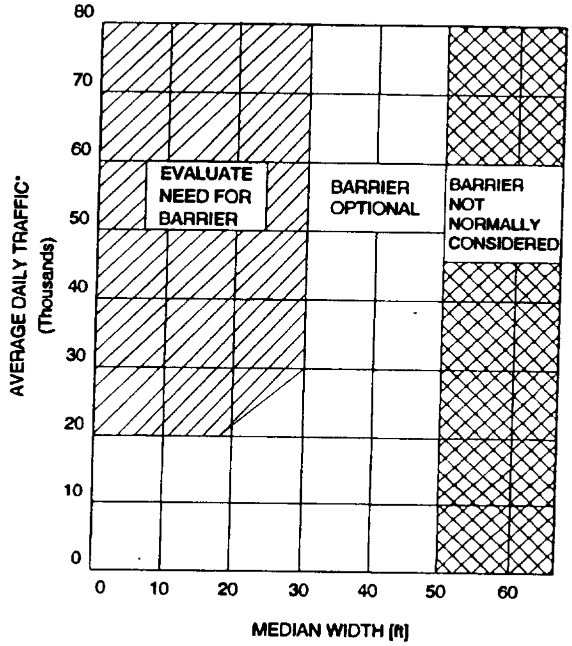

Figure 15. AASHTO Median Barrier Warrant Criteria (*4*).

The median-involved crash frequency models for divided highways with traversable medians provided similar results when compared to the cross-median crash frequency modeling. Median-involved crash frequency models were estimated using data from California, North Carolina, and Ohio. Again, traffic volumes, median width, and median side-slopes were all included in the modeling efforts. Each was found to affect the frequency of median-involved crashes, although to differing degrees. The median width parameter estimates for the median-involved crash frequency models were all negative signifying a relative decrease in accident experience for each unit increase in the median width. The magnitude of the median width parameter estimates, however, were very small (i.e., -0.0002 to -0.004) for each crash frequency model. The parameter estimate for median side-slopes indicates that flattening slope adjacent to the traveled way reduces the frequency of cross-median crashes in California and North Carolina. In Ohio, flattening the adjacent median side-slope was shown to slightly increase the median-involved crash frequency.

Additional median-involved crash frequency models were estimated, specifically for divided highway sections with non-traversable medians and for sections containing median barrier. Data from California, North Carolina, and Ohio were used for both analyses. Results from the non-traversable section analysis indicate that increasing the amount of coverage in the median increases the expected number of median-involved crashes. Also, increasing the elevation difference of the profile grade between opposing travel directions decreases the expected number of median-involved crashes. This finding would suggest that asymmetric medians have a lower crash experience than medians that are symmetric.

Median-involved crash frequency models for sections of divided highway with median barrier were estimated using directional traffic volumes, inside (adjacent to the median) paved shoulder widths, adjacent slopes, and the offset of the longitudinal barrier from the edge of the traveled way as explanatory variables. The traffic volume variable was again highly significant while the remaining variables explained little variation in the expected median-involved crash frequency. The inside paved shoulder width parameter estimate was -0.019 for the California dataset which indicates a relative decrease in median-involved crash frequency for each unit increase in the shoulder width. The parameter estimates for the North Carolina and Ohio datasets were 0.011 and 0.029, respectively, for the inside paved shoulder width. A positive estimate indicates a relative increase in the expected median-involved crash frequency for each unit increase in the inside paved shoulder width. This contradictory finding occurs again when comparing the adjacent slope and barrier offset parameter estimates. Such a result, compared with small effect magnitudes, would tend to indicate that shoulder widths, barrier offset distances, and adjacent slopes have minimal affect on median-involved crash frequency along sections of divided highway with longitudinal median barrier.

A before-after analysis of slope-flattening projects on divided Interstate highways in Iowa was conducted using the EB methodology. There were 18 locations (157 miles) treated over a two-year period – a reference group was selected based on the remaining traversable Interstate highway sections with no median barrier. Treated sites all had symmetric medians with side-slopes of 4:1 in the before period and 6:1 in the after period. Results of the analysis indicate that 14 of 18 sites (77.8 percent) had improved median-involved accident experience as a result of slope-flattening. The median-involved crash experience worsened at the remaining sites. The overall expectation is that flattening side-slopes (symmetric median cross-sections only) decreases the median-involved accident frequency by 12 percent.

Prior to recommending improved median barrier warrant criteria, descriptive measures of median-involved crash severity were determined. These measures were calculated for North Carolina cross-median crashes and for California, North Carolina, and Ohio median-involved crashes. The following summarizes the analysis results:

- For traversable sections with no median barrier in California, the fatal and total median crash involvement is highest for median widths between 11- and 20-feet. Although fatal and total crash involvement is less for sections with median width greater than 20-feet, there is no distinguishable trend.

- For California sections with median barrier, the proportion of fatal and injury crashes (compared to total median-involved crashes) is lowest when the barrier is offset either less than 10-feet or more than 30-feet from the left-edge of the traveled way. This finding is similar for the North Carolina and Ohio barrier sections.

- There is a clear change in median-involved crash severity when comparing median side-slopes that are 6:1 or steeper to those that are flatter than 6:1 in California. However, there is little change in the crash severity measures when comparing different median side-slope categories in North Carolina and Ohio.

- Cross-median crashes and median-involved crashes on traversable sections with no barrier in North Carolina exhibit similar severity measures. When comparing the ratio of fatal and visible injury crashes to total median-involved crashes for various median widths, it is apparent that the severity increases as the median width increases up to 70-feet. For sections with medians greater than 70-feet wide, the crash severity markedly decreases. This same trend occurs with the Ohio median-involved crash data set.

- There is little difference when comparing median-involved crash rates for divided highway sections that are traversable with no longitudinal median barrier to those that have a median barrier with respect to both severity and total involvement.

Based on the analytical results and conclusions drawn from the analysis, improved median barrier warrant criteria were developed. There are two criteria presented (Figures 16 and 17) – the first is based solely on the North Carolina cross-median crash analyses and the second is based on the median-involved crash analyses.

The following discussion is the basis and support for the median barrier warrant criteria presented in Figure 16 (based on cross-median crash analysis):

- The scatter plot shown in Figure 6 indicates that few cross-median crashes occur at locations on divided highways where the average daily traffic volume is less than 10,000 vehicles per day.

- The expected median-involved crash frequency varies little when comparing Tables 5 and 6 which were developed to illustrate the affect that side-slopes have on accident involvement.

- Table B-4 indicates that the total and fatal/A-injury cross-median crash rates are much lower when comparing medians that are greater than 70-feet wide to those that are 70-feet wide or less.

- When comparing the existing AASHTO median barrier warrant criteria to the expected cross-median crash frequencies shown in Tables 5 and 6, the lowest expected frequency in the "Evaluate the Need for Barrier" section occurs when the median is 20-feet wide and the average daily traffic is 20,000 vehicles per day.

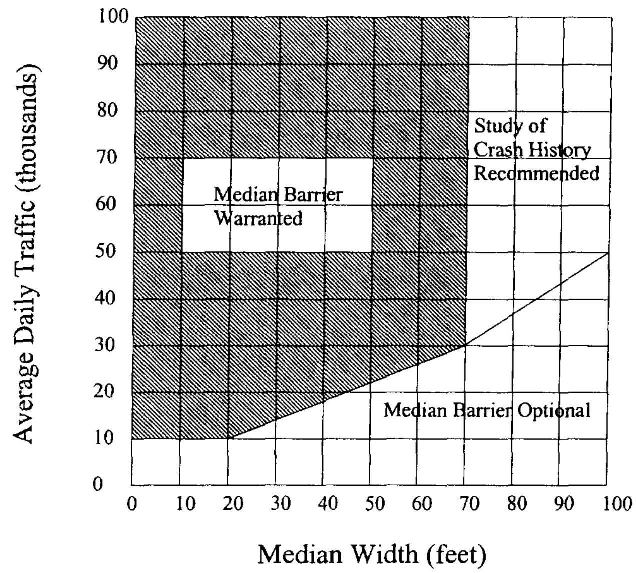

Figure 16. Revised Median Barrier Warrant Criteria
Based on Cross-Median Crash Analysis.

Figure 16 differs from the existing median barrier warrant criteria shown in Figure 15 based on the boundaries at which barrier is warranted. The revised criteria consider median barrier warranted for average daily traffic volumes as low as 10,000 vehicles per day. Additionally, the revised criteria considered barrier to be warranted when the median is up to 70-feet wide.

The following discussion is the basis and support for the median barrier warrant criteria presented in Figure 17 (based on median-involved crash analysis):

- The scatter plots shown in Figures 8 through 10 indicate that few median-involved crashes occur at locations on divided highways where the average daily traffic volume is less than 10,000 vehicles per day.

- The expected cross-median crash frequency does vary when comparing Table 32 to 33 (California data) and when comparing Table 35 to 36 (Ohio data). This indicates that locations with median side-slopes of 6:1 or steeper have higher expected crash frequencies than those with flatter than 6:1 side slopes. In North Carolina, however, there is little support for altering median barrier warrant criteria based on side-slopes.

- The California data indicates that the total median-involved crash rate and fatal and injury crash rate are highest when the median width is between 10- and 20-feet wide. These rates are the lowest when the median is less than 10-feet wide.

- The North Carolina data indicates that the widest medians have the highest crash rates and fatal and injury crash rate.

- The Ohio data indicates that the highway total and fatal and injury crash rates occur when the median is between 61- and 70-feet wide. The lowest rates occur when the median is between 91- and 100-feet wide.

- When comparing the existing AASHTO median barrier warrant criteria to the expected median-involved crash frequencies shown in Tables 32, 33, 34, 35, and 36, the lowest expected frequency in the "Evaluate the Need for Barrier" section occurs when the median is 20-feet wide and the average daily traffic is 20,000 vehicles per day in California; it occurs when the median is 20-feet wide and the average daily traffic is 20,000 vehicles per day in North Carolina; and, it occurs when the median is 20-feet wide and average daily traffic volume is very low (near zero) in Ohio. Based on the data, the expected median-involved crash frequency increases as traffic volumes increase. Increasing the median width has a relatively small affect on crash experience.

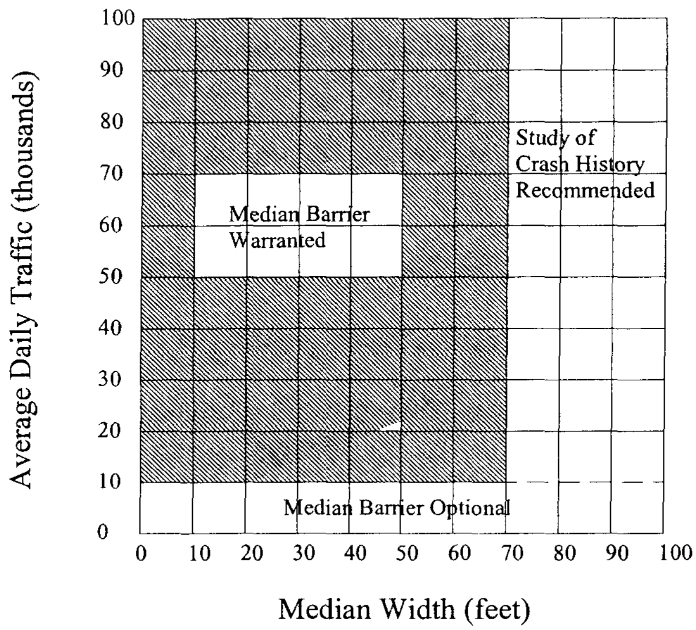

Figure 17. Revised Median Barrier Warrant Criteria Based on Median-Involved Crash Analysis.

The notion that steeper median side-slopes increase crash experience does not change the overall shape of the warrant. The section labeled "Study of Crash History Recommended" should consider the influence of median side-slope during design.

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APPENDIX A

DESCRIPTION OF DATA

This section describes the data that were available to complete the analyses. Included is a discussion of the field-collected cross-section data, electronic roadway inventory data, and electronic crash records from the states of California, Iowa, North Carolina, and Ohio.

FIELD-COLLECTED CROSS-SECTION DATA

Field data from divided highways in California, North Carolina, and Ohio were used to perform median-involved crash analyses. These data were appended to median-involved crash records to form an extract file with crash frequency counts for all sections of divided highway in each state. The distribution of the field data according to median type is shown in Table A-1.

Table A-1. Median Type Distribution of Divided Interstate Highways for which Median Characteristics Data were Collected.

State	Sample Mileage by Median Type			
	Traversable Median, No Barrier	Non-traversable Median, No Barrier	Barrier in Median	Total
California	1,674.0	157.0	611.0	2,442.0
North Carolina	402.0	113.0	200.0	715.0
Ohio	1,208.0	76.0	129.0	1,413.0
Total	3,284.0	346.0	940.0	4,570.0

The data in Table A-1 show that there were a total of 3,282 miles of field-collected data with no median barrier and traversable median cross-slopes. Traversable median cross-slopes were defined as those that were flatter than 3:1 (3 horizontal : 1 vertical). This median characteristic type was important for the analysis because such sections do not prevent errant vehicles from crossing the median and either entering the opposing direction of travel or colliding with objects on the roadside of the opposing travel lanes. There were also 940.0 miles of divided highways for which median characteristic data were collected containing median barrier. Median-related crashes on these sections of highway involve collisions with median barrier in the median, thus preventing full traversal of the median.

The field data collected in California, North Carolina, and Ohio contained the following cross-section information:

- Type of Barrier in Median (concrete, one-sided guardrail, two-sided guardrail, cable).
- Section Length (miles).
- Median Width (feet).
- Adjacent Median Slope (percent).
- Adjacent Slope Length (feet).
- Adjacent Paved Shoulder Width (feet).
- Opposing Median Slope (percent).
- Opposing Slope Length (feet).

- Elevation Difference between Opposing Directions of Travel (none, less than 5 feet, greater than 5 feet).
- Distance to Median Barrier (feet).

The remainder of the field-collected data was for sections of divided highway that did not contain longitudinal barrier, but the median was considered non-traversable. There were 346 miles of such data that were collected in the field. These data were important because non-traversable sections of divided highway do prevent vehicles from crossing the median and colliding with vehicles traveling in the opposite direction; however, such a cross-section does not prevent median excursions. An analysis was needed to understand the frequency of such excursions so that comparisons could be made to traversable and barrier-protected divided highway sections. Again, these data were appended to accident records and electronic roadway inventory data to form a complete database for use in the analysis.

Based on the field data collection effort, roadway sections were defined based on minor changes in the highway driving environment. Minor roadway changes were considered the presence of man-made objects in the median such as a sign or bridge pier or the presence of left-side entrance or exit ramps adjacent to the highway through lanes. The resulting data sets from California, North Carolina, and Ohio contained sections that were all less than one-mile long. The field data collection effort also identified major geometric and cross-section changes in the sample of divided highways. Major geometric and cross-section element changes included changes in median width, median cross-slope, adjacent paved shoulder width, and median type (traversable with no barrier, non-traversable with no barrier, and median barrier sections). Because the original field-collected roadway sections were all less than one-mile long, longer homogeneous sections were created based on major geometric or cross-section changes in the field. In other words, several of the original field data-collected sections with common geometric and cross-section features were collapsed into a longer, homogeneous roadway sections with consistent design features. Descriptive measures of the roadway sections used in the analysis are shown in the "Electronic Crash Data" section of this report.

ELECTRONIC ROADWAY INVENTORY DATA

Because the data collected in the field did not contain traffic volume information, electronic roadway inventory data were obtained from California, North Carolina, and Ohio. All data files contained an estimate of average daily traffic (ADT) volumes for those roadway sections with field-collected data. The traffic volume data were then merged with the field data to form a complete database of roadway information.

Aside from the field data collected in California, North Carolina, and Ohio, the Iowa Department of Transportation provided electronic roadway inventory data for all Interstate highways for the years 1987 through 1996. There were 782 miles of electronic Interstate roadway data available from Iowa for use in a before-after analysis of median cross-slope flattening projects. The following geometric and cross-section information were available in the Iowa electronic records:

- Average Annual Daily Traffic (AADT).
- Percentage of Heavy Vehicles in the Traffic Stream.
- Median Barrier Presence (yes or no).
- Paved Shoulder Width (feet).
- Median Width (feet).
- Route Identification (county, route, begin and end milepost).

ELECTRONIC CRASH DATA

Electronic crash data were obtained from California, Iowa, North Carolina, and Ohio. It should be noted that median-involved crash data were available for all states while cross-median crash data were available only from North Carolina.

Cross-median Crashes

Cross-median crashes were those defined as one in which a vehicle traveling in one direction losses control of a vehicle, enters and crosses the median, and collides with a vehicle or some other object after full-traversal of the median. These crash types were identified by the North Carolina Department of Transportation by review of hardcopy police accident reports and are considered a subset of median-involved crashes.

Between July 1, 1991 and June 30, 1997, there were 1,083 cross-median crashes that occurred on divided highway sections that matched the traversable, divided highway section field data. These data were appended to the roadway inventory data.

Median-involved Crash Data

Median-involved crashes were defined as those in which a vehicle traveling in one direction of travel losses control of the vehicle, enters the median, and is involved in a reportable crash. Median-involved crash data were available from all states cited previously. The following sections describe these datasets for each state.

California

Over a three-year period (1993 through 1995), there were 14,473 median-involved crashes in California that matched the field data sections. Probable median-involved crashes were identified using the following criteria:

- Collision location was beyond median or barrier stripe to the driver's left; or,
- Beyond shoulder to the drivers' left; or,
- Left shoulder area.

The median type variable from the field-collected data was used to distinguish those median-involved crashes on divided highway sections with no longitudinal barrier, those on sections that were considered non-traversable, and those median-involved crashes with median barrier. During the three year analysis period, there were 6,485 median-involved crashes on divided highways with traversable cross-slopes and no median barrier. There were 993 and 6,991 median-involved crashes on non-traversable sections with no barrier and sections with median barrier, respectively.

Iowa

The Iowa Department of Transportation provided all Interstate crash data from 1987 through 1996 for use in a before-after analysis of median slope flattening projects on divided highways. There were nearly 600 miles of divided Interstate highway in Iowa containing no longitudinal median barrier. There were 1,774 median-involved crashes that occurred on these roadway sections – 1,301 were part a reference group while the remainder were included in a treatment group. To identify median-involved crashes, the following protocol was used:

- Eliminate roadway sections that contained median barrier (median barrier = no);
- Crash location = median, shoulder, or roadway;
- Accident type = all types;
- Eliminate all crashes with fixed object location = median or shoulder.

North Carolina

Electronic median-involved crash records from North Carolina were gathered from 1992 through 1994, inclusive. There were a greater number of median-involved crashes per mile when compared to cross-median crashes. A total of 796 median-involved crashes (including 359 cross-median crashes) occurred between 1992 and 1994 on traversable, divided highway sections with no longitudinal median barrier. There were also 296 median-involved crashes that occurred on non-traversable sections with no longitudinal barrier were in the median portion of the cross-section. Lastly, 411 crashes with longitudinal median barrier occurred during the median-involved analysis time period.

Ohio

Over a three-year period (1997 through 1999), there were 5,195 median-involved crashes in Ohio that matched the field data sections. Probable median-involved crashes were identified using the following criteria:

- Divided highway and,
- Full control of access and,
- Number of lanes for both directions of travel on a divided highway greater than 3 and,

- Rural Interstate, urban Interstate, or urban other freeway and expressway and,
- Crash occurrence off left-side or on opposite lane of divided highway or head-on collision.

There were 4,153 median-involved crashes during the three-year analysis period on divided highways with traversable median cross-slopes and no longitudinal barrier. There were 314 median-involved crashes on sections of divided highway with non-traversable medians and there were 728 median barrier crashes on sections with a longitudinal barrier.

APPENDIX B

DESCRIPTIVE MEASURES OF MEDIAN-INVOLVED CRASH SEVERITY

The following sections present descriptive measures of crash severity based on median width, traffic volumes, and median side slopes. The data included were from the states of California, North Carolina, and Ohio.

California

Table B-1 shows descriptive measures of median-involved crash severity on earth-divided, traversable highway sections in California. The data are for the time period 1993 through 1995, inclusive (3 years). The section length, a weighted average daily traffic volume, the frequency of fatal and injury crashes, total median-involved crash frequency, and crash rates are included. The crash rates indicated are per one-hundred million vehicle miles traveled. The column labeled "ratio" is the fatal plus injury crash rate divided by the total median-involved crash rate.

Table B-1. California Median-Involved Crash Severity Distribution (Traversable Sections).

Median Width Range (feet)	AADT Range (veh/day)	Section Length (miles)	Weighted AADT (veh/day)	Median-involved Crashes					
				Fatal	Injury	F + I Rate	Total	Total Rate	Ratio
0 to 10	13,500 – 17,514	5.3	15,684	1	2	3.296	10	10.986	0.300
11 to 20	10,700 – 24,679	33.5	17,516	5	89	14.630	157	24.435	0.599
21 to 30	9,300 – 132,949	77.9	34,333	13	209	7.580	457	15.604	0.486
31 to 40	12,000 – 113,607	252.5	34,899	31	587	6.405	834	8.643	0.741
41 to 50	9,563 – 98,333	311.8	27,327	39	566	6.484	1,198	12.840	0.505
51 to 60	11,500 – 91,915	242.2	37,542	40	392	4.339	855	8.587	0.505
61 to 70	12,000 - 192,457	69.4	41,776	8	149	4.945	285	8.977	0.551
71 to 80	9,700 – 75,778	355.3	26,948	74	728	7.650	1,285	12.257	0.624
81 to 90	8,850 – 86,000	310.3	20,250	60	503	8.183	896	13.022	0.628
91 to 100	12,700 – 66,889	7.6	34,318	0	16	5.602	27	9.454	0.593
> 100	15,200 – 29,000	8.6	24,346	1	15	6.979	31	13.521	0.516
Total				272	3,256	N/A	6,035	N/A	N/A

Based on the descriptive measures shown in Table B-1, there is no trend to indicate a median width that produces significantly less severe median-involved crashes when compared to other median widths. The fatal, injury, and total median-involved crash rates in California are highest for sections with median widths between 11- and 20-feet.

In attempt to identify general crash severity trends for sections of Ohio highways with longitudinal barrier, Table B-2 was created to consider median barrier offset location with respect to the left-edge of the travel way. Fatal and injury median-involved crash rates were calculated based on the section length and traffic volume estimates. The ratio of fatal and injury crashes to total median-involved crashes is also shown in Table 41.

Table B-2. California Median-Involved Crash Severity Distribution (Median Barrier Sections).

Barrier Offset Range (feet)	AADT Range (veh/day)	Section Length (miles)	Weighted AADT (veh/day)	Median-involved Crashes					
				Fatal	**Injury**	**F + I Rate**	**Total**	**Total Rate**	**Ratio**
0 to 10	12,725 – 172,000	198.1	69,171	30	955	6.565	2,146	14.302	0.459
11 to 20	11,600 – 200,426	254.4	71,262	47	1,394	7.259	3,128	15.757	0.461
21 to 30	25,000 – 99,380	131.8	65,680	47	647	7.321	1,436	15.149	0.483
> 30	30,900 – 171,560	26.8	103,925	5	127	4.328	281	9.214	0.470
Total				129	3,123	N/A	6,991	N/A	N/A

A general trend resulting from the severity analysis presented in Table B-2 is that the fatal and injury and total median-involved crash rates are highest for highway sections with barrier offset between 11- and 30-feet from the left-edge of the travel way. These same rates are lowest for sections with median barrier offset 0- to 10-feet or offset more than 30-feet from the travel way. This suggests that placing median barrier less than 10-feet or greater than 30-feet from the left-edge of the travel way is more effective than placing barrier between 10- and 30-feet from the travel way.

A comparison of median-involved crashes on roadway sections with various median side-slopes was conducted using data from California. The results of this analysis are shown in Table B-3. Interpretation of the results indicates that steeper median side-slopes adjacent to the traveled way may increase both median-involved crash severity and the total number of median-involved crashes. The fatal and injury crash rate, and total median-involved crash rate along sections with 4:1 to 6:1 adjacent median side-slopes is 25.08 and 46.08, respectively. When compared to divided highway sections with flatter slopes. A general crash severity or frequency trend does not appear, when comparing successive median side-slope categories in Table B-3.

Table B-3. Comparison of Median Side-Slopes to Median-Involved Crashes in California.

Side Slope Range	Average Median Width (feet)	Section Length (miles)	Weighted AADT (veh/day)	Median-involved Crashes					
				Fatal	Injury	F + I Rate	Total	Total Rate	Ratio
4:1 to 6:1	85.2	14.0	20,810	5	75	25.08	147	46.08	0.544
6:1 to 8:1	79.6	97.0	20,997	17	162	8.03	308	13.81	0.581
8:1 to 10:1	53.9	38.0	27,873	7	96	8.88	201	17.33	0.512
10:1 to 12:1	71.5	61.0	20,284	13	95	7.97	185	13.65	0.584
12:1 to 14:1	57.9	63.7	35,415	12	179	7.73	358	14.49	0.534
14:1 to 16:1	61.1	175.6	24,324	22	339	7.72	652	13.94	0.554
Flatter than 16:1	57.5	1,225.2	30,891	196	2,310	6.05	4,628	11.17	0.541

North Carolina

Table B-4 shows descriptive measures of cross-median crash severity on earth-divided, traversable highway sections in North Carolina. The section length, a weighted average daily traffic volume, the frequency of fatal and severe injury crashes (K+A), total cross-median crash frequency, and crash rates are included. The crash rates indicated are per one-hundred million vehicle miles traveled. The column labeled "ratio" is the K+A crash frequency divided by the total cross-median crash frequency. It is intended to provide a measure of severity level given that a cross-median crash has occurred.

Table B-4. North Carolina Cross-Median Crash Severity Distribution.

Median Width Range (feet)	AADT Range (veh/day)	Section Length (miles)	Weighted AADT (veh/day)	Cross-median Crashes				
				K+A	Rate	Total	Rate	Ratio
0 to 10	N/A							
11 to 20	14,900 – 88,900	74.5	32,193	13	0.248	45	0.857	0.289
21 to 30	13,100 – 128,300	484.1	36,330	93	0.241	385	1.000	0.241
31 to 40	8,900 – 123,000	857.9	21,865	51	0.124	213	0.519	0.239
41 to 50	5,400 – 89,800	199.4	34,333	12	0.080	58	0.387	0.207
51 to 60	14,200 – 88,900	598.6	31,142	41	0.100	184	0.451	0.222
61 to 70	14,200 – 65,400	64.0	28,396	6	0.151	18	0.452	0.334
71 to 80	16,600 – 82,400	160.8	37,680	2	0.015	30	0.226	0.066
81 to 90	14,200 – 120,400	133.7	35,976	6	0.057	29	0.275	0.207
91 to 100	14,800 – 82,400	75.4	30,617	6	0.020	26	0.514	0.039
> 100	8,900 – 117,300	154.8	30,022	9	0.088	61	0.599	0.147
Total				239	N/A	1,049	N/A	

Based on the results of Table B-4, the ratio of cross-median and severe injury crashes to total crashes is highest for medians in the 61 to 70-foot range. Furthermore, these same ratios are very low for medians greater than 70-feet wide when compared to those that are narrower. Table B-5 provides very similar information to that contained in Table B-4; however, the data are for median-involved crashes on traversable, divided highway sections in North Carolina between 1992 and 1994 (3 years). Based on the results in Table B-5 for median-involved crashes, crash severity conclusions are difficult to state because a general trend in crash rate or the ratio of fatal and injury crashes to total crashes does not exist.

Table B-5. North Carolina Median-Involved Crash Severity Distribution (Traversable).

Median Width Range (feet)	AADT Range (veh/day)	Section Length (miles)	Weighted AADT (veh/day)	Median-involved Crashes				
				K+A	Rate	Total	Rate	Ratio
0 to 10	N/A							
11 to 20	15,000 – 78,600	28.1	30,008	1	0.108	28	3.032	0.036
21 to 30	13,100 – 97,400	212.4	34,239	19	0.239	174	2.185	0.109
31 to 40	8,900 – 99,300	371.8	20,081	16	0.196	170	2.079	0.094
41 to 50	13,000 – 77,200	85.8	32,449	5	0.164	57	1.870	0.088
51 to 60	14,200 – 78,600	265.9	29,625	16	0.185	169	1.959	0.094
61 to 70	14,200 – 65,400	27.8	27,336	2	0.240	17	2.043	0.117
71 to 80	16,600 – 74,500	71.2	36,113	5	0.178	45	1.598	0.111
81 to 90	14,200 – 109,300	56.7	34,268	3	0.141	36	1.692	0.083
91 to 100	17,800 – 67,000	30.8	28,623	4	0.414	33	3.418	0.121
> 100	8,900 – 95,000	58.8	27,798	5	0.279	67	3.743	0.075
Total				76	N/A	796	N/A	

In attempt to identify general crash severity trends for sections of North Carolina highways with longitudinal barrier, Table B-6 was created to consider median barrier offset location with respect to the left-edge of the travel way. Again, fatal and severe injury crash rates were calculated based on the section length and traffic volume estimates. The ratio of fatal and severe injury crashes to total median-involved crashes is also shown in Table B-6.

Table B-6. North Carolina Median-Involved Crash Severity Distribution (Median Barrier).

Median Barrier Offset Range (feet)	AADT Range (veh/day)	Section Length (miles)	Weighted AADT (veh/day)	Median-involved Crashes				
				K+A	Rate	Total	Rate	Ratio
0 – 10	16,500 – 85,000	145.9	48,899	2	0.026	41	0.525	0.050
11 – 20	9,000 – 109,300	292.2	39,102	15	0.120	260	2.078	0.058
21 – 30	16,500 – 109,300	125.8	37,329	7	0.136	76	1.478	0.092
> 30	19,100 – 109,300	36.1	46,309	1	0.055	34	1.857	0.003
Total				25	N/A	411	N/A	N/A

A general trend resulting from the severity analysis presented in Table B-6 is that the ratio of fatal and severe injury crashes to total median-involved crashes is highest when longitudinal median barrier is offset 21 to 30-feet from the edge of the travel way. This ratio is lowest when the barrier is offset more than 30-feet from the edge of travel way. There is also evidence from Table B-6 that crash severity and total median-involved crash rate are lowest for highway sections containing median barrier that is between 0 and 10-feet from the left-edge of the travel way. This trend suggests that placing median barrier less than 10-feet or greater than 30-feet from the left-edge of the travel way is more effective than placing barrier between 10- and 30-feet from the travel way.

An analysis of median side-slope crashes was undertaken to determine if there is a relationship between the steepness of slopes adjacent to the left edge of the traveled way and safety. Tables B-7 and B-8 present median side-slope and crash measure information for cross-median and median-involved crashes, respectively. Both tables show the average median width for the sections being analyzed as well as the traffic volume, crash severity, and crash frequency measures. Based on the results shown in Table B-7, there is little evidence to suggest that side-slope negatively affects the frequency of cross-median crashes. This is evidence by comparing the total crash frequency and total crash rate for various side-slope ranges. For instance, the total cross-median crash rate for side-slope between 4:1 (4 horizontal : 1 vertical) and 6:1 is less than the rate for side-slopes between 6:1 and 8:1 or between 8:1 and 10:1, but greater than the rate for side-slopes between 10:1 and 12:1 or between 12:1 and 14:1. Although the ratio of very severe crashes (i.e., fatal and visible injury) to total crashes is highest for the side-slope range of 4:1 to 6:1, comparative analysis does not reveal a trend in this case. Thus, there is little evidence to suggest that steeper median side-slopes increase cross-median crash severity.

Table B-7. Comparison of Median Side-Slopes to Cross-Median Crashes in North Carolina.

Side Slope Range	Average Median Width (feet)	Section Length (miles)	Weighted AADT (veh/day)	Cross-median Crashes				
				K + A	K + A Rate	Total	Total Rate	Ratio
4:1 to 6:1	39.4	46.9	33,359	5	0.125	19	0.475	0.263
6:1 to 8:1	40.5	220.3	32,175	24	0.133	121	0.668	0.198
8:1 to 10:1	47.8	459.3	36,685	52	0.120	245	0.566	0.212
10:1 to 12:1	58.6	547.3	34,457	46	0.095	180	0.374	0.256
12:1 to 14:1	51.9	385.6	28,421	19	0.068	108	0.386	0.176
14:1 to 16:1	47.6	308.4	24,115	25	0.132	105	0.553	0.238
Flatter than 16:1	49.9	835.6	25,182	68	0.126	271	0.504	0.251

Table B-8 contains the same descriptive safety measures as that presented in Table B-7; however, the contents are for median-involved crashes on North Carolina divided highways with traversable medians. Interpretation of Table B-7 indicates that steeper median side-slopes adjacent to the traveled way may increase both median-involved crash severity and the total number of median-involved crashes. Also, the ratio of fatal and visible injury crashes (K+A) to total median-involved crashes is highest for the side-slope range between 4:1 and 6:1. A general trend of decreasing crash severity or frequency does not appear, however, as the median side-slope is flattened.

Table B-8. Comparison of Median Side-Slopes to Median-Involved Crashes in North Carolina.

Side Slope Range	Average Median Width (feet)	Section Length (miles)	Weighted AADT (veh/day)	Median-involved Crashes				
				K + A	K + A Rate	Total	Total Rate	Ratio
4:1 to 6:1	38.7	20.0	31,551	3	0.434	21	3.039	0.143
6:1 to 8:1	38.0	93.6	30,126	5	0.162	61	1.976	0.082
8:1 to 10:1	46.7	197.9	35,312	18	0.235	166	2.169	0.108
10:1 to 12:1	56.7	240.9	32,669	19	0.220	154	1.787	0.123
12:1 to 14:1	52.1	162.5	26,747	6	0.126	104	2.185	0.058
14:1 to 16:1	47.5	133.1	22,284	6	0.185	80	2.463	0.075
Flatter than 16:1	50.1	361.2	23,280	19	0.206	210	2.281	0.090

Ohio

Table B-9 shows descriptive measures of median-involved crash severity on earth-divided, traversable highway sections in Ohio. The data are for the time period 1997 through 1999, inclusive (3 years). The section length, a weighted average daily traffic volume, the frequency of fatal and injury crashes, total median-involved crash frequency, and crash rates are included. The crash rates indicated are per one-hundred million vehicle miles traveled. The column labeled "ratio" is the fatal plus injury crash frequency divided by the total median-involved crash frequency.

Table B-9. Ohio Median-Involved Crash Severity Distribution (Traversable Sections).

Median Width Range (feet)	AADT Range (veh/day)	Section Length (miles)	Weighted AADT (veh/day)	Median-involved Crashes					
				Fatal	Injury	F + I Rate	Total	Total Rate	Ratio
0 to 10	31,123 – 51,939	31.1	44,879	1	58	3.860	196	12.824	0.301
11 to 20	40,058 – 43,112	0.8	41,585	0	1	2.745	5	13.726	0.200
21 to 30	13,810 – 88,898	37.5	39,941	1	45	2.805	104	6.341	0.442
31 to 40	11,495 – 98,844	205.2	34,528	9	164	2.230	450	5.800	0.384
41 to 50	12,600 – 106,455	132.1	57,959	15	352	4.378	814	9.709	0.451
51 to 60	5,690 – 123,146	306.6	33,040	8	339	3.128	743	6.698	0.467
61 to 70	9,663 – 75,822	34.5	33,429	1	82	6.572	210	16.629	0.395
71 to 80	8,912 – 106,851	420.3	40,549	12	583	3.188	1,426	7.641	0.417
81 to 90	10,369 – 52,543	15.9	16,887	2	6	2.721	16	5.442	0.500
91 to 100	51,399 – 156,478	4.0	138,845	1	10	1.809	27	4.440	0.407
> 100	13,620 – 151,306	20.6	91,738	1	64	3.141	162	7.829	0.401
Total				51	1,704	N/A	4,153	N/A	N/A

Based on the descriptive measures shown in Table B-9, there is no trend to indicate a median width that is significantly less severe than another. Like North Carolina, the fatal, injury, and total median-involved crash rates are highest for sections with median widths between 61- and 70-feet in Ohio.

In attempt to identify general crash severity trends for sections of Ohio highways with longitudinal barrier, Table B-10 was created to consider median barrier offset location with respect to the left-edge of the travel way. Fatal and injury median-involved crash rates were calculated based on the section length and traffic volume estimates. The ratio of fatal and injury crashes to total median-involved crashes is also shown in Table B-10.

Table B-10. Ohio Median-involved Crash Severity Distribution (Median Barrier Sections).

Barrier Offset Range (feet)	AADT Range (veh/day)	Section Length (miles)	Weighted AADT (veh/day)	Median-involved Crashes					
				Fatal	Injury	F + I Rate	Total	Total Rate	Ratio
0 to 10	8,056 – 152,625	68.1	81,395	2	159	2.653	351	5.783	0.459
11 to 20	12,600 – 131,215	46.6	77,376	4	143	3.723	306	7.750	0.480
21 to 30	14,465 – 95,206	10.0	75,039	0	28	3.408	58	7.059	0.483
> 30	23,350 – 32,365	4.7	30,075	1	4	3.230	13	8.399	0.385
Total				7	331	N/A	728	N/A	N/A

Again like North Carolina, a general trend resulting from the severity analysis presented in Table B-10 is that the ratio of fatal and injury crashes to total median-involved crashes is highest when longitudinal median barrier is offset 21 to 30-feet from the edge of the travel way. This ratio is lowest when the barrier is offset more than 30-feet from the edge of travel way. There is also evidence from Table 49 that crash severity and total median-involved crash rates are lowest for highway sections containing median barrier that is between 0 and 10-feet from the left-edge of the travel way. This trend suggests that placing median barrier less than 10-feet or greater than 30-feet from the left-edge of the travel way is more effective than placing barrier between 10- and 30-feet from the travel way.

An analysis of median side-slopes in Ohio revealed that the steepest side-slopes (4:1 to 6:1) do not have the highest fatal and injury, or total, crash rate when compared to other median side-slope categories (see Table B-11). Those earth-divided, traversable sections that have an adjacent median side-slope between 12:1 and 14:1 have the highest crash severity and frequency measure. As such, a general trend or relationship between crashes and median side-slopes is not evident from the Ohio data.

Table B-11. Comparison of Median Side-Slopes to Median-Involved Crashes in Ohio.

Side Slope Range	Average Median Width (feet)	Section Length (miles)	Weighted AADT (veh/day)	Median-involved Crashes					
				Fatal	Injury	F + I Rate	Total	Total Rate	Ratio
4:1 to 6:1	52.9	53.4	52,460	5	130	4.40	307	10.01	0.440
6:1 to 8:1	39.8	83.0	41,480	3	108	2.94	243	6.45	0.457
8:1 to 10:1	56.6	190.1	41,052	5	228	2.73	581	6.80	0.401
10:1 to 12:1	49.4	129.4	46,306	9	168	2.70	456	6.95	0.388
12:1 to 14:1	57.9	197.2	31,076	5	354	5.35	801	11.94	0.448
14:1 to 16:1	60.9	154.3	45,289	7	231	3.11	571	7.46	0.417
Flatter than 16:1	60.9	400.8	38,760	17	485	2.95	1,194	7.02	0.420

APPENDIX C
STATE TRANSPORTATION AGENCY QUESTIONNAIRE

Single vehicle run-off-the-road crashes account for nearly one-third of the nation's total fatal highway crashes. Flattening the foreslopes adjacent to the highway travel lanes has long been an acceptable way to reduce the severity of crashes. This assumption is well documented and supported for the area outside (i.e., right of the travel lanes) of the roadway.

A median is that portion of a divided highway that separates opposing directions of travel. The purpose of a depressed median is to provide a recovery area for vehicles that leave the roadway to the left of the travel lanes. Provided that enough recovery area is available, errant vehicles will not enter the opposing travel lanes thus greatly reducing the likelihood of severe head-on or sideswipe crashes. An explicit relationship between foreslopes in depressed medians and safety needs developed. Also, the width of depressed medians without barrier varies based on State Transportation Agency (STA) experience with median-related crashes.

When cross-median crashes occur, longitudinal median barriers are often used to prevent such occurrences. A wide variety of barrier types are available for use depending on site conditions and the intended performance level. The placement location with respect to the travel lanes can change the barrier performance capability.

The American Association of State Highway and Transportation Officials' (AASHTO) *Roadside Design Guide* and *A Policy on Geometric Design of Highways and Streets* provide guidance related to median design. Much of the information contained in these documents, however, may not accurately reflect current field conditions or the current vehicle fleet. **A primary purpose of this survey is to gather information on the current practices, policies, and procedures your STA uses with respect to median design and median barrier use. The information you supply will be used to prepare a report summarizing current practice.**

We request that you forward copies of your current policies, procedures, related standards, samples of pertinent published materials, and website addresses regarding MEDIAN DESIGN PRACTICES in your STA. Please return your completed questionnaire and supporting documents by **March 7, 2003** to:

Eric T. Donnell
BMI
P.O. Box 154
3 Hearthwood Lane
Alexandria, PA 16611-0154

If you have any questions, please contact Mr. Donnell at (814) 880-9757, or e-mail him at edonnell@bmiengineers.com.

Terminology

Median:	The physical separation between opposing directions of travel on a multi-lane, divided highway.
Median Barrier:	A longitudinal system that is intended to prevent errant vehicles from crossing the median and colliding with vehicles traveling in the opposite direction. Median barrier may be flexible, semi-rigid, or rigid.
Median Side Slope:	The ratio of the horizontal distance to the vertical fall for the foreslope of a depressed median. A ratio of 6:1 indicates that the median foreslope falls one foot every six feet of horizontal distance.
Cross-median Crash:	A reportable crash in which a vehicle leaves the roadway to the left, traverses the median, and collides with a vehicle traveling in the opposite direction of travel.
Median Barrier Crash:	A reportable crash where a vehicle leaves the roadway to the left and collides with a longitudinal median barrier adjacent to the travel lanes.

Current Policies and Procedures

The following series of questions is intended to provide information on the current practices, policies, and procedures of your STA with respect to median design and median barriers. Please consider only depressed or flush medians as you reply to the set of questions contained in this section of the questionnaire.

1. Does your STA use the AASHTO *Roadside Design Guide* (RDG) criteria to evaluate the need for median barrier on divided highways (see page 6-2 of RDG for criteria)?

    _____ Yes (If "yes," go to question no. 3)

    _____ No

2. If you answered "no" to question 1, please answer this question. Otherwise, proceed to question 3. If your STA does not use the AASHTO criteria, please list in the table below the factors included in your STA's median barrier warrant and then cite the quantitative level for which a median barrier would be installed (please use additional space if necessary or provide a copy of your criteria when returning the survey).

Median Barrier Warrant Factors	Quantitative Value Required for Median Barrier Installation
Example: Median width	*Example: Install barrier if median width ≤ 40 feet.*

3. Does your STA use the guidelines contained in AASHTO's *A Policy on Geometric Design of Highways and Streets* for divided highway median design (Note: these guidelines apply to new and major reconstruction only and are discussed on pages 341 through 343 of 2001 policy)?

_____ Yes (If "yes," go to question no. 5)

_____ No

4. If you answered "no" to question 3, please answer this question. Otherwise, proceed to question 5. If your STA does not use the AASHTO criteria for median design, please complete the table below by indicating your STA's standard for each design element listed. If other design elements are included in your STA's standard, please write in the design element and then indicate the standard associated with that element.

Median Design Element	STA Standard
Median width	
Median side slopes	
Other:	

5. Using the table below, please indicate which median barrier types are currently approved for use by your STA on divided highways. Then, indicate the minimum width required in the median for the barriers use.

Median Barrier Type	Approved by your STA (please indicate with 'X')?	Minimum Width Required for Use?
Weak-Post, W-Beam Guardrail		
3-Strand Cable, Weak Post		
Box-Beam Barrier		
Blocked-Out W-Beam Guardrail (Strong Post)		
Blocked-Out Thrie-Beam Guardrail (Strong Post)		
Modified Thrie Beam		
New Jersey Shaped Concrete Barrier		
Single Slope Concrete Barrier		
F-Shape Concrete Barrier		
Brifen Wire Rope Safety Barrier		

6. Median barriers may be placed in a variety of locations depending on the conditions present at the installation site. Please list the approved barriers from your STA in the table below and then indicate its most common placement location.

Approved Median Barrier Type	**Most Common Placement Location**

Agency Experience

This set of questions will help us understand your agency's experience with respect to median design and safety.

7. Estimate the number of cross-median crashes that occur in your state annually?

   Annual Number __________

8. Please estimate the proportion of cross-median crashes that are fatal, injury-sustaining, and property-damage only crashes.

   Fatal (%) _____
   Injury (%) _____
   Property Damage Only (%) _____

9. Approximately how many median barrier crashes occur in your state annually?

   Annual Number __________

10. Please estimate the proportion of median barrier crashes that are fatal, injury-sustaining, and property-damage only crashes.

   Fatal (%) _____
   Injury (%) _____
   Property Damage Only (%) _____

11. From the list below, please indicate the two (2) most common causes of median related crashes in your state.

a. Driver lost control of vehicle
b. Driver traveling too fast for conditions
c. Wet, icy or other adverse weather conditions
d. Driver using drugs or alcohol
e. Forced movement or avoidance maneuver
f. Other: ______________________________
g. Other: ______________________________

12. Has your agency ever conducted a study regarding the safety performance of depressed or flush medians on divided highways?

_____ Yes

_____ No (If "no," go to question 14)

Please return a copy of the study with the survey if you answered "yes."

13. If you answered "yes" to question 12, please answer this question; otherwise, proceed to question 14. Was the study that was conducted an attempt to combat median-related crashes?

_____ Yes

_____ No

If "yes," please use the space below to describe the median-related crash problem, the location of the problem, and the conclusion(s) drawn from the study.

14. If your agency has had a median-related crash problem, what has been the most common mitigation measure used to improve the situation?

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15. Please use the space below to describe any innovative median safety treatments that have been employed in your STA. Examples of such practices might include: use of raised medians, use of "new" barrier types, and changing median side slopes.

____

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Please discuss how this innovative treatment has affected median safety?

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16. What documentation (e.g., procedures, policies, research studies, etc.) is available in your State to guide you in median design?

____

____

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____

APPENDIX D
QUESTIONNAIRE RESPONSES

Table D-1. Summary of Questionnaire Responses.

Agency	Question 1	Question 3	Question 7	Question 8		
				Fatal (%)	Injury (%)	PDO (%)
Alabama	Yes	Yes	Not Available	Data Not Available		
Alaska	No	No	Not Available	Data Not Available		
Arizona	No	No	Not Available	Data Not Available		
Arkansas	Yes	Yes	Not Available	Data Not Available		
California	No	No	250	16	58	26
Colorado	Yes	Yes	Not Available	Data Not Available		
Delaware	Yes	Yes	Not Available	Data Not Available		
Florida	No	No	100	18	75	7
Hawaii	Yes	Yes	72	4.2	50	45.8
Indiana	Yes	Yes	Not Available	Data Not Available		
Iowa	Yes	Yes	90	10	45	45
Kansas	Yes	Yes	Less than 10	Data Not Available		
Maine	No	No	Not Available	Data Not Available		
Maryland	No	Yes	100	3	50	47
Massachusetts	Yes	Yes	1 every 3 to 5 years	90	10	0
Minnesota	Yes	No	9	Data Not Available		
Mississippi	Yes	Yes	50	10	60	30
Missouri	Yes	Yes	560	8	49	43
Montana	Yes	No	25	11.5	51.5	37
Nebraska	Yes	Yes	Not Available	Data Not Available		
Nevada	Yes	Yes	47	13	47	40
New Hampshire	Yes	Yes	Not Available	Data Not Available		
New Jersey	Yes	Yes	110	8.3	42.7	49.0
New York	No	Yes	1	Data Not Available		
North Carolina	No	Yes	150 (freeways)	10	40	50
North Dakota	Yes	Yes	Not Available	Data Not Available		
Ohio	Yes	Yes	Not Available	Data Not Available		
Oklahoma	Yes	Yes	200	15	52	33
Pennsylvania	Yes	Yes	60	18	67	15
South Carolina	Yes	Yes	20 – 25 (Interstates)	75	15	10
South Dakota	Yes	No	Not Available	Data Not Available		
Virginia	Yes	Yes	Not Available	Data Not Available		
Washington	No	Yes	150	5	50	45
Wisconsin	Yes	Yes	Not Available	Data Not Available		
Wyoming	Yes	No	16	1.7	41.6	56.6

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 9	Question 10			Question 12
		Fatal (%)	Injury (%)	PDO (%)	
Alabama	Not Available	Data Not Available			No
Alaska	Not Available	Data Not Available			No
Arizona	Not Available	Data Not Available			No
Arkansas	100	1	40	59	No
California	15,000	1	45	54	No
Colorado	Not Available	Data Not Available			No
Delaware	Not Available	Data Not Available			No
Florida	Not Available	Data Not Available			Yes
Hawaii	227	2.2	44.9	52.9	No
Indiana	Not Available	Data Not Available			No
Iowa	5	6	70	24	No
Kansas	Not Available	Data Not Available			No
Maine	Not Available	Data Not Available			No
Maryland	220	1.5	45.6	52.9	No
Massachusetts	1,560	1	47	52	No
Minnesota	1,250	<1	33	67	Yes
Mississippi	150	2	30	68	No
Missouri	754	0.5	39.7	59.8	No
Montana	135	0.5	27	72.5	Yes
Nebraska	18	0.2	39	61	No
Nevada	200	0.5	30.5	69	Yes
New Hampshire	Not Available	Data Not Available			No
New Jersey	2,650	0.4	36.9	62.7	Yes
New York	1382 (reported); Estimate 550 (unreported)	0.2	35	65	No
North Carolina	1,000	1 to 2	33	65	No
North Dakota	Not Available	Data No Available			No
Ohio	Not Available	Data Not Available			No
Oklahoma	680	<0.1	49	51	No
Pennsylvania	1,600	1	55	44	Yes
South Carolina	900	5	10	85	No
South Dakota	Not Available	Data Not Available			No
Virginia	Not Available	Data Not Available			Yes
Washington	1,100	1	41	58	Yes
Wisconsin	1,200	0.1	42	58	No
Wyoming	145	0.5	26.6	72.9	No

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 2
Alabama	Answered "Yes" to question 1.
Alaska	Answered "Yes" to question 1.
Arizona	In rural areas, use the AASHTO median barrier warrant criteria. In urban areas, median barriers are installed on divided freeway sections having median widths of 50-feet and less. Barriers are also considered for medians up to 75-feet wide in urban areas with three or more travel lanes per direction.
Arkansas	Answered "Yes" to question 1.
California	A median barrier study is warranted when traffic volumes exceed 20,000 vehicles per day and the median width is between 0 and 20 feet. In the California median barrier warrant criteria, a study is warranted based on a linear relationship between median width and traffic volume beyond 20 feet and 20,000 vehicles per day, respectively. The upperbound of the relationship occurs at 60,000 vehicles per day and median widths of 75 feet. (See Figure) With any ADT or median width, barriers should be considered if there has been a high rate of out-of-control cross-median accidents involving opposing vehicles. A rate, based on at least three accident in 5 years, of 0.50 cross-median accidents per mile of any severity or 0.12 fatal cross-median accidents per mile per year involving opposing vehicles justifies a median barrier feasibility study.
Colorado	Answered "Yes" to question 1.
Delaware	Answered "Yes" to question 1.
Florida	Median barrier is provided on expressway and Interstate highways where reconstruction reduces the median width to less than the standard for the facility. The following standard median widths apply: (1) Interstate = 64 feet; (2) Freeways with design speed $\geq$ 60 mph = 60 feet; (3) Freeways with design speed < 60 mph = 40 feet; (4) All freeways with barrier = 26 feet (based on 2-foot barrier and 12-foot shoulder).
Hawaii	Answered "Yes" to question 1.
Indiana	Answered "Yes" to question 1.
Iowa	Answered "Yes" to question 1.
Kansas	Answered "Yes" to question 1.
Maine	Median barrier is warranted if the AADT exceeds 20,000 vpd and the median width is less than 6 meters (20 feet). Also, median barrier is warranted if the AADT exceeds 30,000 vpd and the median width is less than 9 meters (30 feet). Median barrier is optional if the AADT is between 5,000 and 20,000 vpd and the median width is less than 6 meters (20 feet). Median barrier is optional if the AADT exceeds 40,000 vpd and the median width is between 9 and 15 meters (30 and 50 feet).
Maryland	The following standard is used by Maryland to evaluate the need for median barrier: • Medians less than or equal to 30-feet and ADT greater than 0, use barrier. • Medians less than or equal to 50-feet and ADT greater than 40,000 vehicles per day, use barrier. • Medians less than or equal to 75-feet and ADT greater than 80,000 vehicles per day, use barrier.
Massachusetts	Answered "Yes" to question 1.
Minnesota	Answered "Yes" to question 1.
Mississippi	Answered "Yes" to question 1.
Missouri	Answered "Yes" to question 1.
Montana	Answered "Yes" to question 1.
Nebraska	Answered "Yes" to question 1.
Nevada	Answered "Yes" to question 1.
New Hampshire	Answered "Yes" to question 1.
New Jersey	Answered "Yes" to question 1.
New York	Median barrier is warranted if the AADT exceeds 20,000 vpd and the median width is less than or equal to 11 meters (36 ft). Median barriers are optional if the AADT exceeds 10,000 vpd and the median width is less than or equal to 1.5 times the narrower clear zone of the two directions of travel (assuming 30 ft clear zones, this distance works out to 45 ft).

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 2
North Carolina	If median width less than 36 ft, use concrete barrier or 2 lines of w-beam strong post. If median width between 36 and 46 ft, use 2 lines of w-beam strong post. If median width between 46 and 60 ft, use 1 line of median cable or 2 lines of w-beam strong post. If median width between 60 and 70 ft, use 1 line of median cable (offset 4-ft from center of median ditch).
North Dakota	Answered "Yes" to question 1.
Ohio	Answered "Yes" to question 1.
Oklahoma	Answered "Yes" to question 1.
Pennsylvania	Answered "Yes" to question 1.
South Carolina	Answered "Yes" to question 1.
South Dakota	Answered "Yes" to question 1.
Virginia	Answered "Yes" to question 1.
Washington	Install barrier if median width is less than 50 feet on fully-controlled access highways.
Wisconsin	Answered "Yes" to question 1.
Wyoming	Answered "Yes" to question 1.

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 4
Alabama	Answered "Yes" to question 3.
Alaska	Answered "Yes" to question 3.
Arizona	Standard is 10:1 median slopes on divided highways.
Arkansas	Answered "Yes" to question 3.
California	In urban areas, the preferred median width is 36 feet (10.8 meters). In rural and suburban areas, the preferred median width is 60 feet (18.6 meters). Median cross slopes of 10:1 or flatter are desirable; slopes of 20:1 are preferred; slopes of 6:1 are acceptable in exceptional cases for drainage or stage construction purposes.
Colorado	Answered "Yes" to question 3.
Delaware	Answered "Yes" to question 3.
Florida	All reconstructed roadways with less than the standard median width contain median barrier. Median barriers are not to be placed on slopes steeper than 10:1.
Hawaii	Answered "Yes" to question 3.
Indiana	Answered "Yes" to question 3.
Iowa	Answered "Yes" to question 3.
Kansas	Answered "Yes" to question 3.
Maine	Typical depressed medians in Maine have 6:1 side slopes for non-barrier sections. The median side slope cannot exceed 10:1 in front of a median barrier. If a steeper slope is used, two separate runs of guardrail should be used instead of a median barrier.
Maryland	Answered "Yes" to question 3.
Massachusetts	Answered "Yes" to question 3.
Minnesota	Depressed medians width standards are 66 to 100 feet (rural). Raised median width standards are 4 to 22 feet. Flush median width standards are 14 feet (painted) to 26 feet (freeway with concrete barrier). Standard median side slopes are 4:1 (minimum) to 6:1 (preferred).
Mississippi	Answered "Yes" to question 3.
Missouri	Answered "Yes" to question 3.
Montana	For depressed medians, the median width ranges from 36 feet (minimum) to 75 feet (desirable). For flush medians, the median width ranges from 4 feet (minimum) to 16 feet (desirable). Standard median side slopes are 6:1. The minimum center longitudinal slope is 0.2 percent.
Nebraska	Answered "Yes" to question 3.
Nevada	Answered "Yes" to question 3.
New Hampshire	Answered "Yes" to question 3.
New Jersey	Answered "Yes" to question 3.
New York	Answered "Yes" to question 3.
North Carolina	Answered "Yes" to question 3.
North Dakota	Answered "Yes" to question 3.
Ohio	Answered "Yes" to question 3.
Oklahoma	Answered "Yes" to question 3.
Pennsylvania	Answered "Yes" to question 3.
South Carolina	Answered "Yes" to question 3.
South Dakota	The preferred median side slope is 6:1; the desirable minimum is 5:1; a minimum side slope of 4:1 may be used; Steeper than 3:1 requires guardrail.
Virginia	Answered "Yes" to question 3.
Washington	Answered "Yes" to question 3.
Wisconsin	Answered "Yes" to question 3.
Wyoming	Recommended median side slopes are 8:1.

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 5	
	Approved Barrier Type	**Minimum Width Required for Use**
Alabama	3-strand cable, weak post	32 feet
	Blocked-out w-beam guardrail (strong post)	8 feet
	New Jersey shaped concrete barrier	6.5 feet
	Single slope concrete barrier	6.5 feet
Alaska	Blocked-out w-beam guardrail (strong post)	Deflection distance is required.
	New Jersey shaped concrete barrier	Deflection distance is required.
	F-shape concrete barrier	Deflection distance is required.
Arizona	3-strand cable, weak post	46 feet
	F-shape concrete barrier	Use on medians less than 30 feet wide.
Arkansas	Single slope concrete barrier	14 feet
	New Jersey shaped concrete barrier	14 feet
California	Blocked-out thrie-beam guardrail (strong post)	Use between 20 and 75 feet
	Single slope concrete barrier	Use between 0 and 36 feet
Colorado	Blocked-out w-beam guardrail (strong post)	28"
	Blocked-out thrie-beam guardrail (strong post)	28"
	New Jersey shaped concrete barrier	Shoulder width
	F-shape concrete barrier	Shoulder width
Delaware	Blocked-out w-beam guardrail (strong post)	10 feet
	F-shape concrete barrier	6 feet
Florida	Blocked-out w-beam guardrail (strong post)	Between 4 and 8 feet, depending on post spacing
	Blocked-out thrie-beam guardrail (strong post)	Between 4 and 8 feet, depending on post spacing
	Concrete barrier	0 feet
Hawaii	Blocked-out w-beam guardrail (strong post)	6.5 feet (2-ft shoulders + width of barrier)
	Blocked-out thrie-beam guardrail (strong post)	6.5 feet (2-ft shoulders + width of barrier)
	Modified thrie beam	7.5 feet (2-ft shoulders + width of barrier)
	New Jersey shaped concrete barrier	6 feet (2-ft shoulders + width of barrier)
Indiana	Blocked-out w-beam guardrail (strong post)	Less than or equal to 30 feet (only used when concrete is not economical or appropriate)
	F-shape concrete barrier	Less than or equal to 30 feet
Iowa	3-strand cable, weak post	22 feet
	Blocked-out w-beam guardrail (strong post)	14.5 feet
	Blocked-out thrie-beam guardrail (strong post)	14.5 feet
	F-shape concrete barrier	No minimum
	Brifen wire rope safety barrier	16 feet
Kansas	Blocked-out w-beam guardrail (strong post)	Requires deflection distance.
	Concrete safety shape (all types)	Use on urban freeways.
Maine	Blocked-out w-beam guardrail (strong post)	26 feet (8 meters)
	Blocked-out thrie-beam guardrail (strong post)	26 feet (8 meters)
	New Jersey shaped concrete barrier	22 feet (6.6 meters)
Maryland	Blocked-out w-beam guardrail (strong post)	Requires deflection distance.
	Blocked-out thrie-beam guardrail (strong post)	Requires deflection distance.
	New Jersey shaped concrete barrier	Requires deflection distance.
	F-shape concrete barrier	Requires deflection distance.
Massachusetts	Blocked-out w-beam guardrail (strong post)	14 feet
	Blocked-out thrie-beam guardrail (strong post)	14 feet
	F-shape concrete barrier	6 feet
Minnesota	Blocked-out w-beam guardrail (strong post)	6 feet
	Blocked-out thrie-beam guardrail (strong post)	6 feet
	F-shape concrete barrier	26 feet

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 5	
	Approved Barrier Type	**Minimum Width Required for Use**
Mississippi	Blocked-out w-beam guardrail (strong post)	24 feet
	Blocked-out thrie-beam guardrail (strong post)	24 feet
	Modified thrie beam	24 feet
	New Jersey shaped concrete barrier	24 feet
Missouri	3-strand cable, weak post	Depends on ADT and speed
	Blocked-out w-beam guardrail (strong post)	Depends on ADT and speed
	Blocked-out thrie-beam guardrail (strong post)	Depends on ADT and speed
	Modified thrie beam	Depends on ADT and speed
	New Jersey shaped concrete barrier	Depends on ADT and speed
	Single slope concrete barrier	Depends on ADT and speed
	F-shape concrete barrier	Depends on ADT and speed
Montana	New Jersey shaped concrete barrier	9 feet (2.8 meters)
Nebraska	3-strand cable, weak post	24 feet
	Blocked-out w-beam guardrail (strong post)	16 feet
	Blocked-out thrie-beam guardrail (strong post)	16 feet
	New Jersey shaped concrete barrier	16 feet
	F-shape concrete barrier	16 feet
	Brifen wire rope safety barrier	Pending NCHRP 350 end treatment approval
Nevada	3-strand cable, weak post	24 feet
	Blocked-out w-beam guardrail (strong post)	Deflection distance.
	Blocked-out thrie-beam guardrail (strong post)	Deflection distance.
	F-shape concrete barrier	Use on medians 26-feet wide or less.
New Hampshire	Modified Thrie Beam	26 feet
	New Jersey shaped concrete barrier	26 feet (normal); 10 feet (minimum)
	F-shape concrete barrier	26 feet (normal); 10 feet (minimum)
New Jersey	Blocked-out w-beam guardrail (strong post)	13 feet
	New Jersey shaped concrete barrier	4 feet
New York	Weak-post, w-beam guardrail	10 to 13 feet (3 to 4 meters) depending on post spacing.
	3-strand cable, weak post	30 feet (9 meters)
	Box-beam barrier	6.5 feet (2 meters)
	Blocked-out w-beam guardrail (strong post)	5 feet (1.5 meters)
	New Jersey shaped concrete barrier	0 feet
	Single slope concrete barrier	0 feet
	F-shape concrete barrier	0 feet
North Carolina	Existing weak-post, w-beam guardrail	N/A
	3-strand cable, weak post	46 feet, 60 feet, 70 feet
	Blocked-out w-beam guardrail (strong post)	36 feet, 46 feet
	New Jersey shaped concrete barrier	Less than 36 feet (freeways)
North Dakota	Box-beam barrier	12 feet
	New Jersey shaped concrete barrier	30 feet
Ohio	Blocked-out W-beam guardrail (strong post)	Requires 5.5 feet of deflection.
	New Jersey shaped concrete barrier	Requires no deflection distance.
	Single slope concrete barrier	Requires no deflection distance.
	Brifen wire rope safety system	Requires 15-foot median width.

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 5	
	Approved Barrier Type	**Minimum Width Required for Use**
Oklahoma	Weak-post, w-beam guardrail	Depends on traffic volume and median width
	Modified thrie beam	Depends on traffic volume and median width
	New Jersey shaped concrete barrier	Depends on traffic volume and median width
	Single slope concrete barrier	Depends on traffic volume and median width
	F-shape concrete barrier	Depends on traffic volume and median width
	Brifen wire rope safety fence	Depends on traffic volume and median width
Pennsylvania	Blocked-out w-beam guardrail (strong post)	Not cost-effective in medians, but may be used based on site conditions.
	F-shape concrete barrier	10 feet
	Single slope concrete barrier	10 feet
South Carolina	3-strand cable, weak post	26 feet
	Blocked-out w-beam guardrail (strong post)	24 feet
	Blocked-out thrie-beam guardrail (strong post)	24 feet
	New Jersey shaped concrete barrier	30 feet
	Single slope concrete barrier	30 feet
South Dakota	Modified thrie-beam	Requires deflection distance.
	New Jersey shaped concrete barrier	Requires deflection distance.
	F-shape concrete barrier	Requires deflection distance.
Virginia	Weak-post, w-beam guardrail	14 feet
	Blocked-out w-beam guardrail (strong post)	6 feet
	F-shape concrete barrier	6 feet
Washington	3-strand cable, weak post	30 feet
	Blocked-out w-beam guardrail (strong post)	Shoulder width
	New Jersey shaped concrete barrier	Shoulder width
	Single slope concrete barrier	Shoulder width
	F-shape concrete barrier	Shoulder width
Wisconsin	3-strand cable, weak post	No standard
	New Jersey shaped concrete barrier	No standard
	Single slope (vertical face) concrete barrier	No standard
	F-shape concrete barrier	No standard
Wyoming	Box-beam barrier	26 feet
	Blocked-out w-beam guardrail (strong post)	26 feet
	Blocked-out thrie-beam guardrail (strong post)	26 feet
	New Jersey shaped concrete barrier	Any width
	F-shape concrete barrier	Any width

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 6
Alabama	Place concrete barrier in the center of the median. Place 3-strand cable 4-feet from the median ditch, on the high side of the superelevation. Place metal guardrail at the shoulder break, on the high side of the superelevation.
Alaska	Attempt to place all barriers in center of median.
Arizona	Place all median barriers in center of median.
Arkansas	New Jersey shaped concrete barrier and single slope concrete barrier are placed at centerline of median.
California	Place concrete barrier in centerline of medians that are less than 36-feet wide. Place thrie-beam barrier in centerline of median when used. Concrete is recommended for medians between 20 and 36 feet; however, thrie-beam may be used if there is a history of significant sand accumulation in the median or if the median is in a designated floodplain.
Colorado	Typically place barrier in center of median or adjacent to shoulder in mountainous areas.
Delaware	The strong-post w-beam guardrail is not used much, but when used is typically placed at the center of the median. The F-shape concrete barrier is a much more common median application and is typically placed at the center of the median.
Florida	Standard roadside barrier offset is the shoulder width plus 2-feet, not to exceed 12-feet from the edge of the traveled way. There is a minimum offset distance for median barriers: (a) zero feet for concrete barrier, (b) 2 to 4-feet for w-beam guardrail, and (c) 2 to 3-feet for thrie-beam guardrail. Barriers are typically located in the center of the median and are not to be located on slopes steeper than 10:1.
Hawaii	Place median barrier at center of median for paved and unpaved traversable medians. Place median barrier adjacent to paved shoulder on unpaved or curbed medians. For slopes flatter than 3:1, the barrier is placed at the hinge point. For slopes steeper than 3:1, the barrier is placed adjacent to the paved shoulder.
Indiana	Concrete barrier is typically placed along paved shoulders. Strong-post w-beam guardrail is used in earth-divided medians as a safety upgrade.
Iowa	Place cable guardrail along edge of shoulder. Place concrete barrier and steel guardrail in center of median.
Kansas	In urban areas, concrete median barrier is placed at center of median with paved shoulders adjacent to barrier. In rural areas, standard median width is 60-feet and no crossover crash problems have been documented thus no median barrier has been installed. The standard median cross-slope in Kansas is 4:1 with flatter slopes being common in rural areas.
Maine	Place median barrier in center of median where appropriate (symmetric median with 10:1 slopes). Use AASHTO *Roadside Design Guide* for sloped medians.
Maryland	Place concrete barrier along edge of paved median shoulder or in center of median. Place w-beam guardrail two feet off edge of paved should (single face) and just offset from the median ditch, at least 14 feet from the edge of the paved shoulder (double face).
Massachusetts	In narrow medians (less than 20-feet wide), place double-faced concrete barrier in center of median. For medians wider than 20-feet, place steel barrier a distance 2-feet offset from the usable shoulder.
Minnesota	W-beam guardrail is typically used along raised medians and for bridge pier protection. Thrie-beam is typically used for bridge pier protection. Concrete barrier is typically placed along the centerline of flush freeway medians.
Mississippi	W-beam and concrete barrier at center of median.
Missouri	Require 12 foot deflection distance and slopes 6:1 or flatter for cable barrier if there is a crossover crash problem. Placement of blocked-out w-beam guardrail requires shoulder slope for placement when the severity of colliding with an obstacle is greater than the severity of an accident with guardrail. Blocked-out thrie-beam is used adjacent to bridges as a transition between the bridge and block-out w-beam guardrail. Modified thrie beam is used between an expressway and an outer road at narrow raised medians. The concrete barriers are used in sections with high ADT and narrow medians.
Montana	New Jersey shaped concrete barrier is common on four-lane rural highways with flush medians less than 10 feet wide – barrier is placed at center of median.

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 6
Nebraska	State standard for median width is 16 feet at expressway intersections, 40 feet on expressways, and 64 feet on Interstates. Standard median side slopes are 6:1. New Jersey shaped concrete barrier is placed on Urban Interstates with medians less than 24 feet wide. Thrie-beam guardrail is used for pier protection. Cable guardrail is considered at high accident locations (e.g., curves).
Nevada	Place F-shape concrete barrier in center of median of narrow medians (26-feet or less) and two feet from the edge of the paved shoulder on wider medians. Place thrie-beam and w-beam guardrail two feet from edge of paved shoulder in all cases. Place 3-strand cable at center of median.
New Hampshire	Modified thrie-beam and concrete barriers are typically placed in center of median.
New Jersey	Place strong-post w-beam guardrail at or near center of medians over 12-feet wide. Place New Jersey shaped concrete barrier at the center of medians that are 4- to 12-feet wide.
New York	Median barriers may be placed on slopes that are 10:1 or flatter. Cable median barrier may be placed on 6:1 slopes. Rigid barriers should not be placed farther than 3 meters (10 ft) from the edge of the traveled way, unless required to be at 3.6 meters (12 ft) by the presence of a 3.6 meter (12 ft) shoulder.
North Carolina	If 2 lines of w-beam guardrail, place barrier on roadway shoulder with 10:1 slopes or flatter. If median cable, place at 4-foot offset from centerline of ditch with slopes of 6:1 or flatter. If concrete barrier, place barrier in center of median with paved shoulder slopes of ½"-inch per foot.
North Dakota	Barrier is placed at center of median.
Ohio	Barriers are typically placed at center of median.
Oklahoma	Barriers are typically placed at center of median.
Pennsylvania	Barrier is placed at center of median.
South Carolina	Barriers are typically placed the shy distance from the travel lanes. The three-strand cable guardrail must be at least 11.5 feet from the edge of travel lanes – this barrier is often offset from the ditch in a symmetric median.
South Dakota	Place at center of median.
Virginia	Place at center of median for symmetric medians; use AASHTO guidance for asymmetric medians.
Washington	Center placement where possible (6:1 side slopes or flatter)
Wisconsin	The standard freeway median width is 60 feet with 6:1 side slopes. The standard expressway width is 60 feet and the side slopes may be either 6:1 (55 mph posted speed) or steeper for posted speeds less than 55 mph (side slopes are protected if steeper than 3:1). The concrete barrier is mostly used in urban areas and in some rural areas with narrow medians (i.e., less than 36 feet). The 3-strand cable guardrail is used in rural or suburban areas with median widths that are wider than 40 feet. Call Patrick Fleming at (608) 266-8486 or e-mail at patrick.fleming@dot.state.wi.us
Wyoming	Place all barriers at center of median.

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 11	
	Most Common Cause of Crash	**Next Most Common Cause of Crash**
Alabama	Driver lost control of vehicle.	Driver traveling too fast for conditions.
Alaska	Data Not Available.	
Arizona	Data Not Available.	
Arkansas	Driver traveling too fast for conditions.	Wet, icy or other adverse weather conditions.
California	Driver lost control of vehicle.	Forced movement or avoidance maneuver.
Colorado	Data Not Available.	
Delaware	Data Not Available.	
Florida	Forced movement or avoidance maneuver.	Driver inattention.
Hawaii	Driver lost control of vehicle.	Driver traveling too fast for conditions.
Indiana	Data Not Available.	
Iowa	Driver lost control of vehicle.	Driver traveling too fast for conditions.
Kansas	Driver inattention.	Driver traveling too fast for conditions.
Maryland	Driver inattention.	Driver traveling too fast for conditions.
Massachusetts	Driver traveling too fast for conditions	Driver using drugs or alcohol.
Minnesota	Driver traveling too fast for conditions.	Wet, icy or other adverse weather conditions.
Mississippi	Driver inattention.	Driver lost control of vehicle.
Missouri	Driver traveling too fast for conditions.	Driver inattention.
Montana	Driver lost control of vehicle.	Driver traveling too fast for conditions.
Nebraska	Driver traveling too fast for conditions.	Forced movement or avoidance maneuver.
Nevada	Driver traveling too fast for conditions.	Driver inattention.
New Hampshire	Driver traveling too fast for conditions.	Wet, icy or other adverse weather conditions.
New Jersey	Driver inattention.	Driver traveling too fast for conditions.
New York	Driver lost control of vehicle.	Forced movement or avoidance maneuver.
North Carolina	Driver lost control of vehicle.	Forced movement or avoidance maneuver.
North Dakota	Data Not Available.	
Ohio	Data Not Available.	
Oklahoma	Driver traveling too fast for conditions.	Driver inattention.
Pennsylvania	Driver lost control of vehicles.	Forced movement of avoidance maneuver.
South Carolina	Driver lost control of vehicle.	Driver traveling too fast for conditions.
South Dakota	Data Not Available.	
Virginia	Data Not Available.	
Washington	Driver traveling too fast for conditions (42%)	Driver using drugs or alcohol (8%)
Wisconsin	Data Not Available.	
Wyoming	Driver traveling too fast for conditions.	Inattentive driver.

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 13	
	Yes/No	Explanation
Alabama	Responded "No" to question 12.	
Alaska	Responded "No" to question 12.	
Arizona	Responded "No" to question 12.	
Arkansas	Responded "No" to question 12.	
California	Responded "No" to question 12.	
Colorado	Responded "No" to question 12.	
Delaware	Responded "No" to question 12.	
Florida	Yes	Beginning in 1991, Florida DOT placed longitudinal barrier on divided highway if the median was narrowed to less than 64 feet. In 2003, the Florida DOT attempted to identify conditions that could reduce the frequency and severity of cross-median crashes without changing the existing median barrier warrant. As a result of the study, Florida DOT is installing median barrier at locations within one mile of interchange ramp termini based on a prioritization scheme.
Hawaii	Responded "No" to question 12.	
Indiana	Responded "No" to question 12.	
Iowa	Responded "No" to question 12.	
Kansas	Responded "No" to question 12.	
Maine	Responded "No" to question 12.	
Maryland	Responded "No" to question 12.	
Massachusetts	Responded "No" to question 12.	
Minnesota	Yes	Study focuses on fatal crashes only. There were a total of 86 fatal crashes during the 10-year period from 1992 through 2001, with 102 reported fatalities.
Mississippi	Responded "No" to question 12.	
Missouri	Responded "No" to question 12.	
Montana	Yes	Fatal crashes where a vehicle crossed a flush 10-foot median prompted the review of median safety practices. The problem area was on Interstate 90 on Lookout Pass by the Idaho border. The review team recommended the installation of concrete median barrier to reduce the frequency of crossover crashes.
Nebraska	Responded "No" to question 12.	
Nevada	Yes	Recently studied crashes caused by vehicles crossing the median to develop a median barrier policy guide in Nevada. The draft guide assesses California's median barrier warrant study and applies to Nevada problems.
New Hampshire	Responded "No" to question 12.	
New Jersey	Yes	In late 2002, two cross-median fatal crashes involving trucks occurred within a day of each other. As a result, the Department developed a program to identify and develop solutions for reducing cross-median crash frequency. Two locations, one each on Interstates 78 and 80, became instant candidates for positive barrier protection. An additional 25 roadway segments have been identified for further study using crash data from 1999 through 2001. These additional sites may warrant positive barrier protection based on a quantitative analysis of heavy vehicle volumes and a flush median width. The analysis is in the early stages, but appears to be a benefit based on the severity of cross-median collisions.
New York	Responded "No" to question 12.	
North Carolina	Responded "No" to question 12.	
North Dakota	Responded "No" to question 12.	
Ohio	Responded "No" to question 12.	
Oklahoma	Responded "No" to question 12.	

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 13	
	Yes/No	Explanation
Pennsylvania	Yes	Study investigated cross-median crash problem on earth-divided Interstate highways. Concluded that cross-median crashes are more frequent during the daytime period and are more likely to involve drunk drivers or snow/icy conditions than other crash types. Also, there is statistical evidence that they are more likely to occur downstream of interchange entrance ramps. Additional data are required, but preliminary evidence is that cross-median crashes are more frequent on roadway sections curved to the right when compared to other sections.
South Carolina	Responded "No" to question 12.	
South Dakota	Responded "No" to question 12.	
Virginia	Yes	In 2002, Virginia DOT assessed the safety performance of Interstate freeway segments with median widths less than 40-feet for the FHWA. This study did not identify the type of crash (e.g., crossover, etc.) for run-off-the-road left (RORL) maneuvers, but only reviewed the severity for designated segments between 1997 and 2001. Based on the evaluation, the Department developed median barrier mitigation methods for those segments not scheduled for improvements in the STIP.
Washington	Yes	It is cost-effective to install median barrier on fully-controlled access highways where the median is 50 feet or less. Online at: http://www.wsdot.wa.gov/eesc/design/policy/pdf/MedianTreatmentStudy.pdf
Wisconsin	Responded "No" to question 12.	
Wyoming	Responded "No" to question 12.	

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 14
Alabama	Install concrete median barrier.
Alaska	No median-related crash problems.
Arizona	Install 3-strand cable as an interim solution – when final lanes are added in the median, an F-shape barrier is installed.
Arkansas	Use concrete barrier wall or guardrail.
California	Most common mitigation measure is median barrier installation.
Colorado	Colorado checks for alignment, design speed, and superelevation issues. If these elements are not contributing to the median-related crash problem, new delineation is added and the shoulder widths are varied.
Delaware	A double-faced guardrail is typically installed for any median less than 40 feet wide for maintenance reasons.
Florida	Install median barrier based on analysis.
Hawaii	Install guardrail after conducting a warrant analysis.
Indiana	Install concrete median barrier in paved medians. Install double-faced w-beam guardrail in grass medians.
Iowa	Install median barrier or flattening median side slopes to 6:1.
Kansas	No median-related crash problems.
Maine	No median-related crash problems.
Maryland	Use of double face w-beam guardrail as median barrier. Use of double face concrete barrier.
Massachusetts	Use AASHTO Roadside Design Guide for barrier warrant with slope flattening.
Minnesota	No mitigation measures used as a result of median-related crash problem.
Mississippi	Installed median barrier at narrow median sites.
Missouri	Once a median-related crash problem area is identified, an analysis is conducted to determine the cause of the problem and identify possible alternatives to correct it. These may include any combination of signing, speed control, pavement marking, shoulder treatments, median slope correction or the placement of median barrier. At present, the most common solution is the placement of median barrier.
Montana	Placement of concrete median barrier rail has been the most common mitigation measure for flush median areas. Slope flattening is a common mitigation measure for depressed medians.
Nebraska	Currently using a temporary New Jersey shaped concrete barrier for temporary urban fix.
Nevada	Use California median barrier warrant guide along sections with crossover crash problem.
New Hampshire	Address crash problem by using advisory speed signs.
New Jersey	Recent accidents have prompted New Jersey to investigate median barrier placement on wide grass medians. The geometric features of the roadway will probably dictate which type of treatment will be employed. It is also possible that in some cases, less costly treatments may be tried such as basic traffic control warning sign enhancements.
New York	No response.
North Carolina	In 1999, North Carolina started an initiative to install median guardrail on existing Interstates and freeways throughout the state. The program includes 991.9 miles of Interstate and freeway facilities – about 815 miles of the program have been complete or let to contract. This program was implemented to improve safety by preventing cross-median crashes. North Carolina incorporates median guardrail on all Interstates and freeways with median widths of 70 feet or less. This includes all new and major re-construction projects.
North Dakota	No mitigation measures used as a result of median-related crash problem.
Ohio	Most medians in Ohio are 60- or 84-feet wide. Where sections of divided highways have a high cross-median crash frequency, cable guiderail has been installed. Additionally, the Brifen wire rope safety fence is also being used at some locations.
Oklahoma	Investigate and install median barrier.
Pennsylvania	Typically install median barrier. Also use shoulder rumble strips on the left (median-side) shoulder as a safety treatment to prevent median excursions.
South Carolina	Installation of weak-post cable barrier (3-strand).
South Dakota	No median-related crash problems.
Virginia	Median barrier is used on medians less than 50-feet wide.
Washington	Median barrier installation.
Wisconsin	Install a barrier wall or 3-strand cable system.
Wyoming	Install a median barrier.

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 15
Alabama	Alabama DOT recently installed, for the first time, a three-strand cable median barrier. It was installed at a location where the median width is 54 feet. The results have been very favorable – there has been one median-related crash since installation and no fatalities. The crash occurred one day after cable installation and the vehicle was able to penetrate the cable.
Alaska	No median-related crash problems.
Arizona	No use of innovative treatments.
Arkansas	No use of innovative treatments.
California	No use of innovative treatments.
Colorado	In urban areas, Colorado may use a raised patterned concrete planter type of barrier to create a defined separation between directions of travel.
Delaware	No innovative treatments.
Florida	No innovative treatments.
Hawaii	Install median rumble strips (no study to evaluate treatment effectiveness).
Indiana	Use of slightly raised medians (1 to 1.5-inch edge height) with corrugations to define the median limits or alert errant drivers. Increase graded median slopes from 8:1 to 12:1 to 6:1 to better re-direct errant vehicles, thus deterring cross-median crashes. No data are available to assess these innovative practices.
Iowa	Will be installing 3.5 miles of Brifen wire rope safety fence along an Interstate near Des Moines, Iowa (Interstate 35) in summer 2003.
Kansas	No median-related crash problems.
Maine	No use of innovative treatments.
Maryland	Adoption of F-shape concrete barrier in lieu of New Jersey shaped barrier as the standard for all temporary and permanent concrete barrier applications.
Massachusetts	Have installed shoulder rumble strips on median-side shoulder of high-speed, divided highways. No statistics available, but appears to reduce median excursions.
Minnesota	Currently exploring alternative median safety treatment applications.
Mississippi	No use of innovative median safety treatments.
Missouri	The bullnose guardrail system is an enclosed guardrail design that wraps a semi-rigid guardrail design around a hazard. It should be used in the medians of expressways or freeways to shield drivers from hazards, such as bridge piers or other obstacles. It is not a crashworthy end terminal, but is rather a non-gating barrier principally constructed of Type E guardrail. As long as the median's vertical differences are minimal or can be graded, the bullnose guardrail system is the preferred treatment for new construction. The bullnose guardrail system requires at least 15 feet (4.5 meters) of median width for its construction. The bullnose guardrail system should not be erected between twin bridges. The Missouri DOT began installation of the bullnose guardrail system in 2002 and no substantial safety records have been generated.
Montana	Have recently been improving Interstate median safety by flattening side slopes.
Nebraska	A 76-foot median Interstate reconstruction is being used. Milled-in rumble strips are being installed on highway shoulders – they have reduced the number of vehicle encroachments into the median. Safety sloped end treatments are being used for drainage pipes in medians – they have lessened crash severity.
Nevada	No innovative treatments.
New Hampshire	No innovative treatments.
New Jersey	New Jersey is in the process of designing two trial installations of median barrier at two Interstate locations: w-beam guiderail and three-strand cable. Benefits will be evaluated after installation of barrier sections.
New York	No innovative treatments.
North Carolina	The median cable guardrail program has reduced the number of annual cross-median crashes from approximately 40 to 15 per year.
North Dakota	Flattening median side slopes to 6:1
Ohio	Ohio DOT has not evaluated the Brifen wire rope safety fence yet.
Oklahoma	Using Brifen wire rope system.
Pennsylvania	No innovative treatments.
South Carolina	Installation of cable barriers has reduced fatalities from crossover median accidents.
South Dakota	No use of innovative treatments.

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 15
Virginia	Using raised medians, F-shaped concrete median barrier, and Tall Wall median barrier. VDOT installed a 54-inch straight face median barrier (42" effective height) on a project at the request of the FHWA. VDOT has installed milled, continuous shoulder rumble strips on both the inside and outside paved shoulders of Interstates. Their effectiveness has not been evaluated to date.
Washington	Using cable median barrier (evaluation is on-going).
Wisconsin	No use of innovative median safety treatments.
Wyoming	No use of innovative median safety treatments.

Table D-1. Summary of Questionnaire Responses (cont'd).

Agency	Question 16
Alabama	AASHTO policy guides.
Alaska	No response.
Arizona	AASHTO policy guides.
Arkansas	No response.
California	California periodically performs a "Median Barrier Study Warrant Review." The last occurrence of this study was 1997.
Colorado	AASHTO policy guides.
Delaware	AASHTO policy guides.
Florida	Florida DOT Plans Preparation Manual
Hawaii	AASHTO policy guides.
Indiana	INDOT Design Manual and AASHTO policies.
Iowa	AASHTO policy guides.
Kansas	AASHTO policy guides.
Maine	Maine has a published "Urban and Arterial Highway Design Guide" as a primary reference.
Maryland	"Guidelines for Traffic Barrier Placement and End Treatment Design."
Massachusetts	AASHTO policy guides.
Minnesota	Minnesota maintains a Road Design Manual and uses both AASHTO policies.
Mississippi	State guidelines follow AASHTO policies.
Missouri	MoDOT Project Development Manual.
Montana	Montana Road Design Manual; AASHTO policies.
Nebraska	Offsetting left-turn bays at median intersections.
Nevada	AASHTO policy guides.
New Hampshire	AASHTO policy guides.
New Jersey	Median barrier design guidelines from other states have been studied, especially those from North Carolina.
New York	Highway Design Manual. Online at: http://www.dot.state.ny.us/cmb/consult/hdmfiles/hdm.html#DOWNLOADING
North Carolina	Roadway Design Manual, Chapter 3, Section 3-6.
North Dakota	AASHTO policy guides.
Ohio	Ohio standards are located in the Location and Design Manual, which is a compilation of the AASHTO policies.
Oklahoma	Oklahoma design manual and AASHTO Roadside Design Guide.
Pennsylvania	Publication 13M (Design Manual, Part 2). Found online at: ftp://ftp.dot.state.pa.us/public/pdf/pricelist.pdf
South Carolina	AASHTO policies and South Carolina Highway Design Manual
South Dakota	AASHTO policy guides.
Virginia	VDOT's Road Design Manual: Online at: http://virginiadot.org/business/locdes/rdmanual-index.asp VDOT's Instructional and Information Memorandum: Online at: http://virginiadot.org/business/locdes/rd-ii-memoranda-index.asp VDOT's Road and Bridge Standards: Online at: http://virginiadot.org/business/locdes/road-and-bridge-standards.asp
Washington	State Design Manual Chapter 700 contains median design policies. Online at: http://www.wsdot.wa.gov/fasc/EngineeringPublications/Manuals/MedianBarrierGuidelines.pdf http://www.wsdot.wa.gov/fasc/engineeringpublications/designmanual.htm

Table D-1. Summary of Questionnaire Responses (concluded).

Agency	Question 16
Wisconsin	Wisconsin has experienced recent median crossover crashes with resulting deaths which have increased our interest in median barrier treatments. One drunk driver, crossover crash killed two young children on Interstate 43 north of Milwaukee and generated median and political reaction that lead to installation of 20,600 feet of three-strand cable in the center of a 64-foot wide median. However, our standard median barrier policy has been to follow the Roadside Design Guide. We have decided on an interim policy to require median barrier installation on freeway construction having less than a 60-foot median width and high average daily traffic similar to the California warrant chart. We have noted with interest more restrictive guidance being implemented by some states and have decided to join the states contributing to the NCHRP 17-14 in hope of gaining national review and updated guidance for median width and barrier treatments.
Wyoming	AASHTO policy guides.

APPENDIX E

FOLLOW-UP PHONE INTERVIEW QUESTIONS AND RESPONSES

The questionnaire was intended to gather information about State Transportation Agency (STA) median design and safety policies and procedures; approved median barrier type and placement guidelines; and, innovative safety treatments that states use to prevent median-related crashes. In the case of 21 STAs, the questionnaire responses were unique in the sense that more detail was sought regarding a specific median design or safety practice. As such, telephone interviews were conducted to gather this information. The telephone interview results are shown below.

Alabama

Question: A response to the questionnaire indicated that 3-strand cable was recently installed along a section of divided highway in Alabama. On which highway was it installed and why was the cable installed (e.g., history of median-involved crashes)?

Answer: Barrier was installed along a 10-mile section of Interstate 10 in Mobile County. Cable was installed cable high crash frequency and severity. For a period of several years prior to installing the barrier there were two or three fatalities annually as a result of crossover crashes. Cable rail was cheaper and provided less rigid system than steel or concrete barriers. There were 45 hits during construction (1 year period) and 30 hits since May 2002 when construction was complete – no fatalities since during of since completing of the installation. The Alabama Department of Transportation has a maintenance contract ($25,000 per year) for repair of the system.

Question: A response to the questionnaire indicated that concrete median barrier is the most common mitigation measure when a median-related crash problem exists in Alabama. Why?

Answer: Typically cross-median crashes occur on high volume roadways with wide medians (e.g., 54-feet). In such cases, a lane addition project is undertaken that narrows the median to 30-feet or less. A concrete barrier is then installed in the center of the median.

Alaska

Question: Based on review of the Alaska DOT Preconstruction Manual, it appears as though the concrete safety shape and w-beam guardrail are approved for use in the State as median barriers. Where would these barriers typically be placed (e.g., center or near edge of shoulder)?

Answer: Typically place median barrier near the centerline, especially if median slopes are flatter than 6:1.

Question: Does Alaska have recommended median side slopes for depressed sections? Are there standard median widths for divided highways?

Answer: Typical slopes are 6:1 in depressed medians – no standard median width for divided highways.

Arizona

Question: A response to the questionnaire did not indicate a minimum or desired median width for use of the three-strand cable or F-shape barrier, do you have desired widths for their use?

Answer: The cable barrier is used on medians that are 46-feet or wider and placed at least 12 feet from edge of the paved shoulder. The F-shape concrete barrier is used on medians that are typically less than 30-feet wide. All cable barrier placement is preferred on median side slopes that are 6:1 or flatter with 10:1 being preferred. Arizona is considering the use of the Brifen wire rope safety fence.

Colorado

Question: A response to the questionnaire indicated that w-beam guardrail is used along roadsides -- are there any median applications in Colorado? It was also indicated that concrete barriers are used in medians – can you describe where they are typically placed in reference to the travel lanes?

Answer: There are w-beam applications in the eastern part of state where medians are wider and the terrain is level. Most median barrier treatments in the western part of the state are the concrete safety shape. Concrete barriers are typically offset the width of the paved shoulder from the travel way, usually 2- to 4-feet.

Question: A response to the questionnaire indicated that Colorado checks alignment, design speed, and superelevation issues as the most common mitigation measure for median-related crashes. If these elements are contributing to the median-related crash problem, new delineation is added and the shoulder widths are varied.

Answer: This mitigation measure essentially widens the median. For instance, a divided highway may initially be constructed with two 12-foot lanes per direction and an 8-foot outside shoulder and a 4-foot inside shoulder. If a median-involved crash problem exists, the cross-section may be painted to include two 12-foot lanes and a 6-foot shoulder both on the inside and outside of the through travel lanes.

Question: A questionnaire response indicated that in urban areas Colorado may use a raised patterned concrete planter type of barrier to create a defined separation between directions of travel. How effective is this treatment compared to normal median barrier applications?

Answer: This application is more typical in urban low-speed settings to control access while providing aesthetic appeal – this treatment is not used on high-speed, access-controlled highways.

Florida

Question: Other than the study that was provided regarding across-median crashes, is Florida doing anything innovative with respect to median safety (i.e., new barriers, raised medians, etc.)?

Answer: No innovative treatments are being used in Florida to reduce across-median crashes. However, across-median crashes appear to be more frequent near interchanges thus Florida is considering barrier at such locations.

Question: In the across-median study, the need for median barrier is based on crash history. Can you elaborate (based on frequency, severity, hazard index, etc.)?

Answer: It is based on crash frequency and field reviews.

Hawaii

Question: A questionnaire response indicated that Hawaii installs rumble strips as an innovative median safety treatment. Please explain.

Answer: Rumble strips are located on the paved shoulder adjacent to the median.

Iowa

Question: A questionnaire response indicated that the Brifen wire rope safety fence will be installed along a 3.5-mile section of Interstate 35 in summer 2003. Why did Iowa select the Brifen system in favor of other median barrier types?

Answer: Traffic volumes and speeds are high as this is a heavy commuter route into Des Moines. There are also 3 interchanges within the 3.5-mile Brifen installation. Crash data indicates heavier concentrations of cross-median crashes near interchanges, probably due to weaving and other maneuvering. Cable systems are arguably safer in that they offer a more flexible and forgiving impact. Oklahoma DOT has had 140+ impacts on their 7-mile installation and only one minor injury. Higher tension and 4th cable reduces the likelihood of a vehicle under-riding the cable, which has occurred with the standard 3-strand cable system. Also, selected Brifen for ease of maintenance--posts can be manually replaced and cable systems cause less snow drifting. Cost was also a consideration, as this was much cheaper than concrete barrier with paved median and storm sewer.

Question: What site characteristics exist at the site where the Brifen system will be installed?

Answer: Median width is 50 feet; median cross-slopes are 6:1 with a few feet of differential grade in some areas. The installation line will be on the outside edge of the high-side shoulder, 11 feet off the edge of the traveled way.

Maryland

Question: Can you please forward a copy of your recently published "Guidelines for Traffic Barrier Placement and End Treatment Design?"

Answer: Received – see report for details.

Minnesota

Question: Does Minnesota have a typical or standard median width for urban freeways?

Answer: Depressed medians are preferred on urban and rural freeways. Flush medians may be used in urban areas if the drainage ditch of a depressed median is too shallow or the side slopes are too steep. The desirable rural median width is 66-feet; a minimum dimension for urban freeways is not available.

Question: A questionnaire response indicated that concrete median barrier is the only treatment for flush medians, the w-beam guardrail is used for raised medians, and metal guardrails are used for bridge pier protection. What barrier type would be use for depressed medians? Where would it be placed?

Answer: Common longitudinal median barriers are three-strand cable guardrail, strong-post metal plate guardrail, and F-shape concrete median barrier. Provided that the median side slopes are 10:1 or flatter, the barriers are typically located in the center of the median. The AASHTO Roadside Design Guide median barrier placement guidelines are followed in the event that the barrier cannot be located at the center of the median.

Question: You indicated that a median-related crash study was undertaken that focused on fatal crashes. What was result of study? Do you have a report?

Answer: Between 1992 and 2001, there were 86 fatal cross-median crashes that claimed 102 lives. This accounted for 12 percent of fatal crashes on divided highways in Minnesota during this time period. Minnesota is currently using the AASHTO Roadside Design Guide to evaluate the need for median barrier, but has undertaken a study to determine where guardrail is required to prevent cross-median collisions. They are targeting high accident locations and are identifying locations where median barrier offers a benefit.

Question: A response indicated that Minnesota is exploring alternative median safety treatment applications. Which ones?

Answer: Currently exploring use of metal tension cable guardrail (i.e., Brifen system or SAFENCE or Marion Steel).

Missouri

Question: In the NCHRP survey question dealing with approved median barrier types and the minimum width required for their use, you answered that the width required for use depends on the speed and ADT. Do you have general guidelines?

Answer: There are no general guidelines – only the information that is contained in the AASHTO Roadside Design Guide is used as barrier selection criteria.

Question: A response to the questionnaire indicated that the Missouri DOT may use mitigation measures other than installation of median barrier (e.g., speed control, signing, slope correction, shoulder treatments, etc.) for sections of divided highway with median-related crash problems. Have you documented the benefits of these alternative mitigation measures?

Answer: No documented benefits, but may try some of the low-cost mitigation measures before installing barrier. Evaluations may be performed at the district-level.

Question: A response to the questionnaire indicated the use of the bullnose guardrail system in Missouri. Do you have pictures or standard specifications or drawings of the system? Also, can you offer any anecdotal comments about the benefits of installing such a system?

Answer: Sent standard drawing/detail of bullnose (see report for details). The bullnose is used to shield bridge piers that are constructed in medians on divided highways and has been very effective.

Montana

Question: A questionnaire response indicated that the Montana DOT may flatten slopes as a mitigation measure for sections of divided highway with median-related crash problems. Are there quantitative or anecdotal findings to support this?

Answer: No quantitative findings are available; however, the perception is that flatter slopes reduce the frequency of median crossings.

Question: What has been your States experience on I-90 (Lookout Pass) since issuing the report?

Answer: No evaluation after barrier was installed in 1999.

Nebraska

Question: A questionnaire response indicated use of the 3-strand cable and Brifen wire rope guardrail systems. Are there any documented advantages or disadvantages of their use?

Answer: Nebraska is not yet using the Brifen system, only considering it for use. The three-strand cable system costs less than the w-beam and thrie-beam guardrail. Additionally, striking the cable barrier results in less vehicular damage when compared to other median barriers. The disadvantage associated with the cable barrier is that it requires 12-feet of lateral distance behind it for deflection and it is difficult to provide enough tension on the inside of horizontal curves.

Question: Where will Nebraska place the Brifen wire rope system after it is approved for use?

Answer: Still awaiting for a NCHRP 350 approved end treatment before installing Brifen system – no decision has been made about the location of the first application.

Question: A questionnaire response indicated that milled-in shoulder rumble strips are reducing the frequency of median encroachments. By what percent?

Answer: Nebraska has only been installing milled-in shoulder rumble strips for about 1.5 years and thus do not have any documented safety benefits.

Question: A questionnaire response indicated that safety sloped end treatments are being used for drainage pipes in medians and their use has lessened crash severity. Can you discuss this application?

Answer: The safety sloped end treatment is a 15- to 20-foot long end treatment used in the median to shield drainage culverts. Because of the length, the slope of the treatment is approximately 10:1 instead of the 3:1 found on most end treatments. The flatter slope may lessen crash severity because the slope on the end treatment matches the median side slope.

New Jersey

Question: A questionnaire response indicated that the New Jersey DOT is investigating two trial installations of median barrier along two Interstate locations. The barrier types are the modified thrie-beam and three-strand cable. Can you offer more detail (e.g., which Interstate, how wide is the median, why were these sites selected)?

Answer: The three-strand cable will be installed on Interstate 78 between mileposts 23.3 and 24.48 (48-foot wide median). The modified thrie-beam will be installed on Interstate 80 between mileposts 27.2 and 28.16 (56-foot median). These sites were selected based on ease of installation and accident history.

Question: A questionnaire response indicated that a methodology has been developed to identify and develop solutions for reducing cross-median crash frequency. This process requires distinguishing roadway segments that are candidates for positive barrier installation. Using three years of crash data (1999 through 2001), approximately 25 locations were identified for further study. Can you provide more detail about your screening process?

Answer: The screening process involved determining the frequency of cross-median crashes that occur during a three year period. All divided highways were broken into two-mile sections. If four or more cross-median crashes occurred in a two-year period, the section has been set aside for further study.

Question: Based on a response to the questionnaire, it was noted that a series of quantitative parameters were used to identify high cross-median crash locations. Would you please discuss these parameters and the values for which high-risk locations were identified?

Answer: Phase II of the study will involve a review of cross-median crash site conditions in an attempt to identify geometric elements or traffic characteristics that are common. Such an evaluation would permit a second screening process to be carried out with the intent to program median barrier installation at locations with greater risk of cross-median crashes.

New York

Question: Based on a response about approved median barriers in New York, you are one of few states that use weak-post w-beam guardrail and three-strand cable for median barrier applications. How extensive is the use? What are the advantages and disadvantages of each system?

Answer: Neither barrier is very common. The weak-post w-beam is a treatment that has existed on many rural divided highways for many years. If no cross-median crashes problems exist at locations with the weak-post system, the barrier has not been replaced with a more rigid system. Both barrier types have advantages – they may be located far from the travel lanes and are somewhat flexible. Neither is good at redirecting large trucks.

Nevada

Question: A questionnaire response indicated that Nevada uses the AASHTO policies for median design and safety; however, you also indicate that you have drafted a median barrier guide based on California's median barrier warrant study. Can you please explain?

Answer: Nevada is in the process of reviewing Caltrans' median barrier policy – if approved, the Caltrans policy will replace the AASHTO policy for use by Nevada DOT. Currently, median-involved crashes are evaluated based on both policies.

North Dakota

Question: A questionnaire response indicated that North Dakota is flattening median side slopes to prevent median-related crash problems. Have you performed any evaluations to determine what effect this treatment has on median-related crashes?

Answer: If median widths are less than 6-feet, North Dakota uses concrete barrier. If greater than 6-feet, box beam barrier is used. ND has only has about 20 miles of box beam and less than 10 miles of concrete barrier. Slope flattening has been limited and no evaluation has taken place to evaluate the effectiveness.

Ohio

Question: The question related to common placement locations was not answered as intended. Can you explain where median barriers are placed in the cross-section (e.g., near shoulder, center of median, etc.)

Answer: Most medians are 60-feet wide and for such cases Ohio installs double-faced steel guardrail. In certain cases, Ohio adds lanes to the median and thus reduces the width to 36 feet – here, a concrete barrier would be used and the median paved. In all cases, barriers are commonly placed at the center of the median.

Question: A questionnaire response indicated that the Ohio DOT is using the Brifen wire rope safety fence at locations with high crash frequencies. Where is it being used and do you have photographs or anecdotal comments?

Answer: The Brifen system was recently installed along a 10-mile section of Interstate 75 north of Cincinnati in a 60-foot median. There are no quantitative findings to date about the barrier effectiveness.

Oklahoma

Question: A questionnaire response indicated that the median barrier type and placement location is dependent on the traffic volume and median width. Do you have standards or guidelines to follow?

Answer: Oklahoma use AASHTO Roadside Design Guide for barrier placement recommendations. Generally, Oklahoma tries to place median barrier in the center of the median if it's symmetric. Barrier is commonly placed adjacent to shoulder in asymmetric medians.

Question: A questionnaire response indicated that Oklahoma uses the Brifen wire rope safety fence. Do you have any quantitative or anecdotal findings of its effectiveness?

Answer: The barrier was placed adjacent to the paved inside shoulder of the southbound lanes of the Lake Hefner Parkway. There was a crossover crash problem (5 or 6 head-ons collisions in 2 years) and the Brifen system has solved all problems (no crossovers since installation in 3 years). See report for more details.

Question: You indicated that you investigate and install median barrier when a crash problem exists. Can you please elaborate?

Answer: Example of crash analysis is Lake Hefner Parkway. A median-involved crash problem existed and consequently a 1000-foot experimental section of the barrier was installed in 2001, then another 6.3 miles added in August 2001. The median width is variable but ranges from 36 to 42 feet. From 1997 to 2000, 185 crossovers reported with 6 fatalities and 77 injuries. After one year of installation, there were 128 impacts, 43 were potential crossovers with no serious injuries. Maintenance is a real benefit of the system. Oklahoma is considering more installations.

South Carolina

Question: A questionnaire response indicated that cable guardrail is being used to reduce median crossover crashes in South Carolina. Do you have documented, quantitative benefits of this program? Where is the barrier being placed in the median?

Answer: The three-strand cable guardrail is placed at least 11.5 feet from the edge of the travel lane closest to the median so that when struck the errant vehicle will not encroach on the travel lane. The cable system is not typically located in the center of the median because drainage issues dictate not doing so. The metal and concrete barrier systems are typically placed at the shy line distance or greater from the edge of the travel lane. In certain instances, the South Carolina has added travel lanes in the median so the shy distance criterion is violated.

Virginia

Question: Does the Virginia DOT have standards or guidelines for median barrier placement location?

Answer: See Road Design Manual – it is available on-line. Generally follow AASHTO guidelines.

Question: A questionnaire response indicated that the Virginia DOT studied crash severity on Interstate freeway segments and developed barrier mitigation methods for those segments not included in the STIP. Can you further explain the study and results?

Answer: In 1997, FHWA asked the Virginia DOT to study narrow medians (40-feet or less). No crash study results are available -- the outcome of the effort was installation of strong-post w-beam beam guardrail along a section of Interstate 95 in Greensville County.

Question: A questionnaire response indicated that median barrier is used in medians less than 50-feet wide. Was a study conducted to develop this criterion?

Answer: An internal decision was made to develop this criterion. A significant number of States have studies median-related crash experience and Virginia's criterion may have been influenced by these findings.

Question: A questionnaire response indicated that the FHWA requested the installation of a 54" straight face median barrier on a 1-mile project in Virginia for study purposes only. Can you comment on the barrier effectiveness?

Answer: FHWA did testing on an experimental barrier in Virginia; however, the results or outcome of this testing are unknown.

Wisconsin

Question: Please explain typical median barrier placement locations in Wisconsin. Also, can you describe the purpose and benefits of installing the three-strand cable barrier in Wisconsin?

Answer: The cable barrier is installed on 4-miles of Interstate 43 (64' median with) – the side slopes are generally between 6:1 and 10:1. Wisconsin is now requiring cable on medians less than 60-feet wide on newly constructed divided highways. Wisconsin is beginning a median barrier retrofitting study similar to that performed in North Carolina.

The cable barrier was installed in September 2002. There have been no hits since installation. The county maintains the system.